APPENDIX A
UPDATES AND REVISIONS TO THE MRBCA TECHNICAL GUIDANCE

The department seeks to maintain a viable, relevant, and effective Missouri Risk-Based Corrective Action (MRBCA) process with the flexibility necessary to meet changing environmental conditions and regulations. In addition, we expect that department staff and users of this guidance will identify areas of needed improvement over time. This appendix provides a framework for updating this guidance. Changes in the guidance will also be reflected in changes to the associated risk-based rules to the extent necessary to implement changes in the guidance. We envision three kinds of updates.

The first type of update addresses errors, omissions, clarifications or corrections to this guidance that do not involve substantive issues. These kinds of changes will be made as determined to be necessary by the Department of Natural Resources and as quickly as possible. We anticipate these changes to be handled by means of an "Errata Notice" that can be inserted into the document and that will be posted on the MRBCA web site maintained by the department.

The second type of update would be more substantive technical or policy issues that interpret or build upon the current technical guidance. As long as the change did not conflict with existing laws and regulations, substantive changes Will be made through the use of Technical and Policy Memoranda that will be posted on the MRBCA web site.

The third type of update will encompass a complete review that responds to changes in scientific knowledge, improved methodologies, and new and better information. Every three years, the department will initiate this systematic review and evaluation of this guidance. The first complete review and evaluation will begin three years from the date of final publication of this guidance. It should be staggered with any review of the risk-based corrective action guidance that covers the petroleum storage tanks so that the reviews are not on going in the same time period. Any changes made in the guidance will need to be conducted in accordance with any required regulatory procedures.

The review will be done through a public participation process and in concert with a stakeholder group that, at a minimum, is comprised of relevant federal, state and local agencies, regulated entities and their representatives, and interested citizens. The review planning process will identify and plan for areas of responsibility, a timeline for completion, quality control procedures, and a publication mechanism.

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APPENDIX B
DEFAULT TARGET LEVELS AND TIER 1 RISK-BASED TARGET LEVELS

Appendix B has been updated and, therefore, because of its size, has been removed from this April 2006 version. The entire revised appendix is available on the MRBCA web page.

APPENDIX C
ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

C.1 BACKGROUND

When performing a risk assessment, it is assumed that a receptor would typically be exposed to chemicals of concern (COCs) over a defined geographical area, for a specified exposure duration, and through one or more routes of exposure. The geographical area and the exposure duration for a receptor may vary for different routes of exposure. The geographical area over which a receptor is exposed to COCs is called the exposure domain. Because COC concentrations typically vary over the exposure domain and exposure duration, it is necessary to estimate a representative COC concentration consistent with the receptor's exposure domain and exposure duration. For purposes of calculating the representative COC concentration for risk assessment purposes, the area of impact(s) within the exposure domain should be used if the exposure domain is larger than the area of impact(s). This avoids the potential for inappropriate "dilution" of the representative concentration that can result from inclusion of non-detect values outside the area of impact and helps to address any concerns associated with use of "average" concentrations in MRBCA in lieu of the more traditional 95% Upper Confidence Limit (UCL) concentration approach articulated in EPA guidance.

A representative COC concentration is the average concentration to which the receptor is exposed over the specified exposure duration, within a specified geographical area, and for a specific route of exposure. In most risk assessments, the exposure point concentration is assumed constant over the exposure duration.

Representative concentrations are necessary for both the "backward" and "forward" mode of risk assessments. The backward mode of risk assessment results in target levels for each complete route of exposure identified in the exposure model and each COC. Representative concentrations are used in the risk management step in which the target concentrations are compared with the representative concentrations. The forward mode of risk assessment results in the calculation of risk for each complete route of exposure identified in the exposure model, and representative concentrations are used to estimate risk.

The calculation of representative concentrations is complicated by several factors. These include:

- Spatial variability in the concentrations,
- Temporal variability in the concentrations, and
- Lack of sufficient site-specific concentration data.

Further complication arises because environmental data is typically obtained through biased sampling in that the sampling is focused on identifying the source areas and extent of contamination and does not consist of samples collected systematically over the exposure domain (area of impact). Additional complications arise because the concept of representative concentration is often associated with a site as opposed to an exposure pathway and receptor. Because several complete pathways may exist at a site, several representative concentrations, one for each complete pathway, must be estimated for each receptor. This appendix discusses the methodology used to estimate the representative concentrations for each complete route of exposure.

The calculation of the representative concentration requires the following steps for each receptor:

1. Identification of all of the media of concern. Typically these include surficial soil, subsurface soil, soil up to the depth of construction, and groundwater,
2. Identification of all the complete routes of exposure under current and future conditions,
3. Identification of the exposure domain (area of impact) for each media identified in Step1, and each complete route of exposure identified in Step 2,
4. Identification of the COC concentration data available within the exposure domain (area of impact) for each media, and
5. Calculation of the representative concentration, which would be the average of the data from Step 4 above.

When using the average concentration as the representative concentration, the value should not be artificially lowered or "diluted." To avoid this, the following should be kept in mind (also refer to Section 9.5, Recommend the Next Course of Action):

1. Do not use data beyond the exposure domain (area of impact) unless there is not enough data within the domain and data is available just outside the domain. If data is available just outside the exposure domain, judgement should be used whether to interpolate and use this data or to collect additional data within the exposure domain.
2. Within the area of impact, replace the non-detect values with half the detection limit. Concentrations with a J laboratory qualifier, which is a judgement made at the laboratory, should use the laboratory-estimated value.
3. As a simple or red flag check, determine if the maximum concentration of any COC exceeds ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration within an area of impact, not the site-wide maximum concentration. Possible reasons for an exceedance could be:
   - The maximum concentration is an outlier,
   - The average concentration was inaccurately calculated,
   - The area of impact is not adequately characterized, or
   - A hot spot may not have been adequately characterized.
4. If the representative concentration is based on extrapolation using a model, the model must be supported by site-specific data.
5. When calculating the representative groundwater concentration, first estimate the average concentration in each well based on recent data, assuming data from multiple events is available, and then use the average of each well to estimate the representative concentration.
6. If free product is present at a monitoring point, use the effective solubility or effective vapor pressure to estimate the concentration at that point.
7. For wells with multiple years of groundwater data, use the most recent two years of data to estimate the representative concentration. In certain cases, data that is more than two years old may be used, but it must be justified (also refer to C.2.4.1).

8. If the area of impact is smaller than the exposure domain, the exposure factors may be modified (in Tier 3 evaluation) to account for this circumstance. .
9. For the subsurface-soil-to-indoor-inhalation pathway, do not use soil data collected below the water table. Similarly, for the groundwater-to-indoor-inhalation pathway, groundwater data from the first encountered saturated zone must be used.

C.2 CALCULATION OF REPRESENTATIVE CONCENTRATIONS

C.2.1 Surficial Soil (0-3 feet below ground surface)

The Missouri Risk-Based Corrective Action (MRBCA) process requires the evaluation of four routes of exposure associated with surficial soil:
1. The ingestion of COCs in groundwater due to leaching of residual COCs present in the surficial soil,
2. Accidental ingestion of soil,
3. Outdoor inhalation of vapors and particulates from surficial soil emissions, and
4. Dermal contact with surficial soil.

The latter three pathways are combined and referred to as the "direct contact with soil" pathway. Thus at least two different surficial soil representative concentrations are required, one for leaching to groundwater and one for direct contact with soil. In certain cases, depending on use and characteristics of the site, a single representative concentration may suffice for both pathways.

C.2.1.1 Representative Surficial Soil Concentration for Leaching to Groundwater

The exposure domain for this pathway is the area of impact through which leachate generation may occur and COCs can migrate to the water table. The representative surficial soil concentration should be calculated using the surficial soil data collected within the are of impact. Thus, prior to calculating the representative concentration, it is necessary to clearly define the horizontal extent of the impacted area and to identify the surficial soil data available within this area.

C.2.1.2 Representative Concentrations for Direct Contact Pathway

The representative surficial soil concentration (0 to 3 feet)is based on the area of impact - that is, the area of the site over which the receptor might be exposed to contaminated surficial soil. The exact exposure domain of the receptor is difficult to estimate because the assumption is that the receptor is exposed over a period of time equal to the exposure duration. In the absence of specific information about the receptor's activities, the area(s) of impact should be considered the receptor's exposure domain. For potential future exposures and in the absence of any engineering controls, it may be necessary to assume that exposures that might otherwise be prevented/minimized (e.g., due to paving) will need to be evaluated as if exposure to contaminated surficial soil will occur.

To calculate the representative concentration for the direct contact pathway, one must

1. determine the extent of impact,
2. estimate the receptor's exposure domain(s), and
3. determine the number of soil samples available within the area of impact or the number of samples necessary to adequately represent the area of impact .

For a non-resident worker, the average concentration over the area of impact may be used. For a child receptor, the maximum concentration must be used and, therefore, a representative concentration need not be calculated if a child is an actual or potential receptor. For direct soil contact pathway for a construction worker, refer to Section C.2.3.

C.2.2 Subsurface Soil (greater than 3 feet below ground surface)

The MRBCA process includes the following two routes of exposure associated with subsurface soil: (i) leaching of residual COC concentrations in the subsurface soil to groundwater, and (ii) indoor inhalation of vapor emissions. Thus, a representative concentration must be calculated for each complete pathway. Calculation of additional representative concentrations may be required if the assumptions for current and future site conditions are different.

C.2.2.1 Representative Subsurface Soil Concentration for Protection of Groundwater

The representative concentration for this pathway should be the average concentration in subsurface soil measured within the area of impact.

C.2.2.2 Representative Subsurface Soil Concentration for Protection of Indoor Inhalation

Subsurface soil concentrations protective of indoor inhalation are estimated using an emission model such as the Johnson and Ettinger (2001) model. This model assumes that chemicals volatilize from the subsurface soil source, travel vertically upwards without any lateral or transverse spreading, and enter the building through cracks in the foundation and floor. To ensure consistency with the model, the representative concentration for this pathway should be based on soil concentrations measured directly below or immediately adjacent to the footprint of the enclosed space.

To evaluate the potential future indoor inhalation pathway, (i.e., an enclosed structure is constructed over contaminated soil), the size (footprint) and location of the planned structure must be estimated. In the absence of site-specific information regarding planned structures, the future location and size of the structure must be approximated based on the evaluator's professional judgement. A conservative option is to locate the hypothetical structure over the area of impact (that is, the area of maximum COC concentrations). However, this is only one conservative option and its applicability will vary from site to site. For sites where the footprint of a current on-site structure is or might be different from that of a structure erected in the future, a representative subsurface soil concentration must be calculated for both the current and potential future structure.

To estimate the representative concentration, the evaluator must:
1. Identify the footprint of the structure within which the receptor is located,
2. Identify the footprint of the potential future enclosed structure,
3. Identify the soil concentration data available within each of these two footprints, and
4. Calculate the average of these concentrations.

If sufficient data are not available within the building footprint, data collected within 20 feet of the building footprint may be used to calculate average COC concentrations in soil. Data from locations beyond the 20 foot building footprint buffer may be considered/needed in cases where preferential pathways such as soil macropores, utility conduits, or soil fractures may cause vapor migration towards the building. Generally, vapor concentrations are expected to decrease with increasing distances from the source. When calculating the representative concentration, a horizontal attenuation factor may be applied to concentrations that are more than 20 feet from the building footprint, if adequate technical support is provided for derivation of the attenuation factor.

If several samples within and adjacent to the building footprint are available, more weight should be given to the samples collected within the footprint. Two scenarios are possible: (i) the building footprint is located entirely within the contaminated area, and (ii) the building footprint is partially located within the contaminated area. For both scenarios, the representative soil concentration would typically be based on data collected within and directly adjacent to the footprint of the building. In the second scenario, the representative concentration may differ from that calculated in scenario one because a portion of the structure lies over uncontaminated soil.

C.2.3 Representative Concentration for Construction Worker

The MRBCA process requires the evaluation of the following three routes of exposure for the construction worker:
1. Accidental ingestion, dermal contact and outdoor inhalation of vapors and particulates from soil,
2. Outdoor inhalation of vapors from groundwater, and
3. Dermal contact with groundwater.

Thus three representative concentrations are required. Each of these is discussed below.

C.2.3.1 Representative Soil Concentration

For the construction worker, no distinction is made between surficial and subsurface soil because, during construction, the construction worker might be exposed to both. To estimate the representative concentration for the construction worker, it is necessary to identify the (i) depth of construction, (ii) areal extent of construction, and (iii) the horizontal and vertical extent of soil impacts within the area of construction including the number of samples available to calculate the representative concentration within the zone of construction . The potential future depth of construction should be estimated based on the likely type of structure that might be built and by identifying the typical depth of utilities on and adjacent to the site. If the areal extent of the construction area is not known, a conservative option (not the only option), would be to assume that the construction zone will be entirely within/across the area of impact. The representative concentration would be the averaged concentration within this zone of construction.

C.2.3.2 Representative Groundwater Concentration

As with estimating representative soil concentrations, it is necessary to estimate the areal extent of the construction zone and identify the groundwater data available for this zone. The representative concentration would then be calculated as the average concentration within this zone. Temporal variations in groundwater concentrations should be evaluated as discussed in Section B.2.4.1. If contaminated groundwater is known to be present just below the depth of planned construction (as opposed to within the depth of planned construction), best professional judgement should be used in deciding if outdoor inhalation of vapors from groundwater should be evaluated

C.2.4 Groundwater

The MRBCA process requires the evaluation of the following three routes of exposure associated with groundwater:

1. Ingestion of groundwater,
2. Dermal contact with groundwater, and
3. Indoor inhalation of vapor emissions from groundwater (only from shallow groundwater).

Where multiple aquifers are present, the shallowest aquifer would be considered for the volatilization pathway. The specific aquifers that are or might be used for domestic use or in another manner in which dermal contact could occur must be considered for the ingestion and dermal contact pathways. Representative concentrations must be calculated for each aquifer and associated exposure pathway(s).. Thus, depending on the number of complete pathways, up to three different groundwater representative concentrations, one for each complete pathway, must be calculated.

C.2.4.1 Representative Demonstration Well Concentration for Protection of Groundwater Ingestion (Drinking Water Pathway)

For the ingestion of groundwater pathway, maximum contaminant levels (MCLs) or, where MCLs are lacking, calculated risk-based concentrations, must be met at the point of exposure (POE) well. Often the point of exposure well is hypothetical and, therefore, data for the POE might not be available. During the course of groundwater remediation, one or more point of demonstration (POD) wells must be identified, target concentrations calculated and the POD well(s) monitored to ensure that unacceptable exposures do not occur at the POE..

The representative concentration at the POD and POE should be calculated based on measured COC concentrations in groundwater, as discussed below.

- If COC concentrations in groundwater are stable, the representative concentration is the arithmetic average of the most recent data collected over a period of no more than two years on at least a quarterly basis.

- If COC concentrations are decreasing, the representative concentration is the arithmetic average of the most recent data collected over a period of no more than one and one-half years on at least a quarterly basis.

- If COC concentrations are increasing, the arithmetic average of the most recent data collected over a period of no more than one year on at least a quarterly basis.

C.2.4.2 Representative Groundwater Concentration for Protection of Indoor Inhalation

Groundwater concentrations protective of indoor inhalation are typically estimated using a model such as the Johnson and Ettinger (2001) model. This model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe and the vadose zone and into the enclosed space. Thus, representative concentrations for this pathway should be based on groundwater concentrations measured within the footprint of the building or up to 20 feet from the building. As mentioned above for soil, data beyond 20 feet may be considered/necessary based on the presence of features in vadose zone soils (e.g., macropores, fractures, utility conduits, etc.) that could influence vapor migration. Refer to Section C.2.2.2 for a discussion of the evaluation of future structures and their relationship to the area of impact.

For the groundwater to indoor air pathway, multiple representative concentrations might be needed if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings, one on-site and one off-site, a representative concentration would have to be calculated for each building.

After identifying the location of the building footprints (whether real or hypothetical) and the available groundwater monitoring data within or adjacent (within 20 feet and in some cases up to or more than 100 feet) to each footprint, the average concentration within each footprint must be estimated, as discussed in Section C.2.2.2. However, groundwater data may not be available for each footprint; therefore, several options are available. These include:

1. Installation of additional monitoring wells within or adjacent to the footprint lacking data,
2. Interpolation or extrapolation of existing data (in the case where the plume originates

under a building, extrapolated data gathered from areas adjacent to the footprint may not be adequate) or,

3. As a conservative approach, use of data from wells located upgradient of the building that are between the building and the source of contamination.

C.2.4.3 Representative Groundwater Concentration for Dermal Contact

The average concentration of COCs in the groundwater that a receptor might come in contact with is used as the representative concentration. Note that temporal variations in COC concentrations will be considered as discussed in Section C.3. More than one representative concentration might be needed where a receptor might contact groundwater from more than one aquifer or saturated zone.

C.3 GENERAL CONSIDERATIONS FOR CALCULATING REPRESENTATIVE CONCENTRATIONS

As discussed in this document, calculation of representative concentrations requires considerable professional judgement. Prior to performing the computations identified in Section C.2, the following should be considered:

- Evaluate whether the spatial resolution of the data is sufficient. While an exact number of samples cannot be specified herein due to the variability in conditions from site to site, data should be available from known or likely impacted areas within the various receptors' exposure domains.

- If the data are old (greater than four years old) and the COC concentrations exceed Tier 1 Risk Based Target Levels, new data may be collected (especially groundwater data). If a new release has been documented, new data must be collected in order to characterize adequately the nature and extent of the current impact. If old data are to be eliminated from the risk evaluation, the reason for elimination must be clearly documented in the Tiered Risk Assessment Report (see section 7.2 of the MRBCA guidance).
- Non-detect soil and groundwater samples located at the periphery of the area of impact should not be used.
- Non-detect results associated with certain COCs within the exposure domain (area of impact) should be replaced by half the detection limit. In this context, certain COCs refers to those constituents that are below analytical detection limits in a particular sample but are within a known area of impact based on other COCs associated with that sample that are present above analytical detection limits. For example, if vinyl chloride was not present in a sample above its analytical detection limit but TCE was present above its limit, then for that sample one-half the detection limit for vinyl chloride would be used in figuring the average concentration of vinyl chloride since, based on the TCE detection, the sample is considered to be within an area of impact. This differs from the approach of using one-half the detection limit for samples where all COCs were non-detect. In that case, none of the sample results should be used to figure the average since that sample is not considered to be within an area of impact.

- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole within the area of impact/exposure domain, the average concentration of these samples may be used.
- The maximum concentration of any COC within the area of impact should not exceed ten times the representative average concentration. If this situation occurs, further evaluation of the analytical data to assess its usability may be necessary.
- In certain cases, an area-weighted average may be a better estimate of the representative concentration. An area-weighted average differs from an arithmetic average in that it considers the area over which an individual measurement applies as opposed to assuming equal weighting of all individual results. For example, if sampling has been focused on establishing the maximum concentration present (hot spot) and the limits of impact (horizontal and vertical extent), there may be limited concentration data available for the area of impact in between these two extremes. In these cases, the results may need to be "area weighted" so that the resulting average is not skewed in a particular direction for risk assessment purposes. For example, if a single hot spot sample concentration is averaged with multiple edge of impact concentrations, the resulting average could be biased on the low side if a simple arithmetic average is used. If a gridded sampling pattern has been used to sample soil, the arithmetic average is a good approximation of the area-weighted average. However, if a biased sampling pattern has been used, then it may be necessary to use an area-weighted average to accurately determine the representative concentration. There are different ways to calculate weighted averages across an area of impact. For relatively simple situations with few samples, a calculation methodology such as the Thiessen Polygon Method could be used. However, in the majority of cases, it will likely be more efficient to use available computer software to contour areas of impact and automatically perform area weighted average concentration calculations. Prior to performing any area-weighted average calculations, the remediating party should discuss the specifics with the project manager.

The following considerations are necessary to evaluate representative groundwater concentrations.

- To account for temporal variations in groundwater concentrations, the representative concentration in a well may be estimated as follows:
  1. If COC concentrations in groundwater are stable, the arithmetic average of the most recent data collected over a period of no more than two years on at least a quarterly basis.
  2. If COC concentrations are decreasing, the arithmetic average of the most recent data collected over a period of no more than one and one-half years on at least a quarterly basis.
  3. If COC concentrations are increasing, the arithmetic average of the most recent data collected over a period of no more than one year on at least a quarterly basis.

  Data from wells on the periphery of the area(s) of impact having COC concentrations consistently below detection limits cannot be used in the calculation of representative groundwater concentrations.

- For wells that contain or have contained free product within the most recent two years, the concentration representative of those chemicals comprising the free product in the well should be the effective solubility of the various chemicals comprising the free product.

Table C-1
Calculation of Representative Concentrations

Route of Exposure	Calculation of Representative Concentration
Surficial Soil (0 to 3 feet bgs)	
Soil concentration protective of leaching to groundwater or surface water body	Average of surface soil concentrations collected within the area of impact.
Direct contact with soil including ingestion of soil, dermal contact with soil, and the outdoor inhalation of vapors and particulates emitted by surficial soils	Average of the surface soil concentrations within area of impact for non-residential receptor. <u>Maximum concentration</u> for child receptor.
Subsurface Soil (greater than 3 feet bgs)	
Indoor inhalation of vapor emissions	Average of the subsurface soil concentrations collected below or within 20** ft of the real or hypothetical footprint of the building (Excluding concentrations below water table and capillary fringe).
Soil concentration protective of leaching to groundwater	Average of the subsurface soil concentrations within the area of impact (Excluding concentrations below water table and capillary fringe).
Groundwater	
Indoor inhalation of vapor emissions	Average of the groundwater concentrations within 20** feet of the footprint of the real or hypothetical building
Dermal contact with groundwater	Average of the groundwater concentrations that a receptor may come in contact with
Groundwater domestic use pathway	
• Concentration at POE	Average of the groundwater concentrations*
• Concentration at POD	Average of the groundwater concentrations*

*: Refer to Section C.2.4.1.
**: Refer to discussion in Section C.2.2.2.

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APPENDIX D
PROCEDURE FOR REVIEW OF RISK-BASED CORRECTIVE ACTION (RBCA) DECISIONS

Introduction

With the advent of this new RBCA guidance in Missouri, occasions for questions and differences between the department, owners, consultants and others over site-specific decisions will occur. Most differences will likely be resolved at the Project Manager level. This procedure lays out a process for resolving differences that cannot be resolved between the Project Manager and the remediating party. To be effective, the review process must be thorough, impartial and timely.

Who may request a RBCA Review?

The remediating party directly affected by a RBCA decision may request a review.

What decisions may be reviewed?

Any written decision of the Project Manager, including those transmitted via e-mail, regarding the applicability of the Missouri RBCA guidance or rules to a specific site being addressed under those rules or guidance. Likely areas of review will be decisions related to site characterization work plans and reports, site conceptual model/risk assessment reports, corrective action work plans and reports, activity and use limitations and long-term stewardship.

Evaluation by Unit Chief

Where the final decision in question is made by a Project Manager at the "staff" level, the remediating party (Requester) shall contact the Project Manager's immediate supervisor and request an evaluation of the matter, before initiating a written request for a RBCA Review. The process for this may be any that is mutually agreeable to all parties. For example, a phone conference between the Requester and the Unit Chief, with or without the Project Manager, may serve to resolve the issue. When contacted for an evaluation, the Unit Chief must make every effort to address the matter and render a decision in a timely fashion. The Unit Chief will convey the decision to the remediating party in written form.

Requesting a RBCA Review

If the Requester feels that the response from the Unit Chief is not satisfactory or timely, or if the decision in question is made by a Project Manager at the Unit Chief level, the Requester may initiate a RBCA Review. This review is initiated by submitting the relevant information on the attached form "Request for RBCA Review" or through some other means that provides the same information. The request shall include a written summary of the matter and include supporting documentation as needed, or refer to such documentation that may be in the department's files. When using supporting documentation, the Requester shall point to the specific pages, sections or items that are relevant. The request must be submitted in writing or via e-mail.

The request shall go first to the Section Chief over the Project Manager who rendered the decision in question. The Section Chief may either attempt to resolve the matter through the RBCA Review Process or may refer the matter immediately to the Program Director. The Section Chief may solicit the review and input of other section chiefs. If referring immediately to the program director, the Section Chief shall do so within three working days of receipt.

If the Requester does not agree with the findings of the Section Chief, the Requester may ask in writing or by e-mail that the Program Director review the matter.

The RBCA Review Process

The Reviewer (Section Chief or Program Director) shall review the file and impartially consider the relevant facts. The Reviewer shall discuss the substance of the Request for Review with the Requester at a mutually acceptable time and manner. The Requester may bring technical consultants and the Reviewer may include the Project Manager and other technical staff. Attorneys or other legal staff shall not participate, either for the Requester or the department, except by mutual agreement of all parties. The reviewer shall carefully and without partiality to department staff consider the facts and viewpoints of both sides and make every effort to take into account the meaning and intent of the written RBCA guidance.

The Reviewer shall provide a written decision summarizing the issue under review, the relevant facts of the decision, the rationale behind the decision and any information or considerations outside of the specific situation that were used in making the decision.

The Requester shall not unreasonably expand the original scope of the request except by mutual agreement, until the program has issued a final decision on the original request.

The decision of the Program Director is a final decision and may be appealed. Any decision made within the Hazardous Waste Program (HWP) may be appealed to the Hazardous Waste Management Commission.

Any written decision shall be retained in the HWP file for the site as a public record under the Sunshine Law. The HWP shall maintain a compendium of review decisions made under this process. The compendium shall be updated regularly and posted to the department's web site, and shall serve as a reference document when the RBCA guidance and rules are updated.

RBCA Review Process vs. Formal Appeal

This appendix describes an informal and voluntary review process. It is provided as a means of both working through differences between the department and the remediating party without time-consuming and expensive litigation. It is also a means for the department to review substantial decisions for relevance to other sites and to provide consistency in decision-making.

This informal review process does not substitute for or replace the formal appeal process to the Hazardous Waste Management Commission under 640.010 RSMo, in which an appeal is treated as a contested case. It does not substitute for administrative or judicial dispute resolution procedures available under applicable federal laws and regulations.

Timeframes

A Requester must file a Request for RBCA Review within ninety (90) days of the original decision except in the case of a "clean letter" or "no further remedial action letter," in which case the Requester must file the request within thirty (30) days. The Section Chief will respond with a final decision within forty-five (45) days of receipt of the request.

If the Requester disagrees with the Section Chief's decision, he or she may request a review by the Program Director within sixty (60) days of the Section Chief's decision.

The Program Director as Executive Director will respond with a final decision within forty-five (45) days of receipt of the request.

These timeframes may be extended by mutual agreement of all parties.

Request for Review of RBCA Decision

Requester Info	Requester Contact Info________________________________ Date of Request _____________ Address____ Telephone Number __________________________________ Name of Site Date Received by HWP Address of Site____ Summary of Issue (To be Completed by the Requester; Use extra pages, attachments as necessary) I hearby request a RBCA review of this matter by the Hazardous Waste Program Requester Signature____________________________________ Date______________________
Section Chief	Section Chief: Summary of Findings and Comments (Use additional pages as necessary) S.C. Signature_____________________________________ Date____________________
Program Director	Program Director: Findings and Comments (Use additional pages as necessary) P.D. Signature_____________________________________ Date____________________

E.1 INTRODUCTION

Appendix E provides the inputs required to calculate default target levels (DTLs) and Tier 1 risk-based target levels. Several of these parameters, as explained in Section 9.0, may also be used in Tier 2 evaluation. Specifically the calculation of the Tier 1 risk-based target levels and the Tier 2 and 3 site-specific target levels requires the following:

- Acceptable risk level,
- Chemical-specific toxicological factors,
- Physical and chemical properties of the chemicals of concern (COCs),
- Receptor-specific exposure factors,
- Fate and transport parameters, and
- Mathematical models.

Each of these factors is discussed below. In addition, this appendix discusses the target levels for lead (Section E.10) and the estimation of risk and target levels when light or dense non-aqueous phase liquid (LNAPL/DNAPL) is present on/in the groundwater (Section E.11).

For Tier 1 risk assessments, Tier 1 risk-based target levels have been calculated by the department for each of the COCs, the receptors (child, adult resident, age-adjusted resident, non-residential worker, and construction worker), and the following exposure pathways using conservative assumptions applicable to most Missouri sites.

<u>Pathways for Surficial Soils, defined as 0 to 3 feet below ground surface (bgs)</u>

- Leaching to groundwater and potential use of groundwater,
- Leaching to groundwater and subsequent migration to a surface water body, and
- Ingestion of soil, dermal contact with soil, and outdoor inhalation of vapors and particulates emitted by surficial soils.

<u>Pathways for Subsurface Soils, defined as greater than 3 feet bgs to the water table</u>

- Volatilization and upward migration of vapors from subsurface soil and potential indoor inhalation of these vapor emissions,
- Leaching to groundwater and potential use of groundwater, and
- Leaching to groundwater and subsequent migration to a surface water body.

<u>Pathways for Groundwater</u>

- Volatilization and upward migration of vapors from groundwater and potential indoor inhalation of these vapor emissions,
- Volatilization and upward migration of vapors from groundwater and potential outdoor inhalation of these vapor emissions,
- Ingestion, inhalation and dermal contact of water if the domestic use of groundwater pathway is complete,

- Dermal contact with groundwater, and
- Migration to a surface water body and potential impacts to surface waters.

The following pathways for surface water and sediments are not included in Tier 1 calculations:

- Ingestion of surface water,
- Contact with surface water during recreational activities (ingestion, inhalation of vapors, and dermal contact),
- Ingestion of fish, and
- Contact with (accidental ingestion and dermal contact with) sediments.

Other Pathways

In a Tier 2 assessment, leaching to groundwater, horizontal migration of the plume under a building, and volatilization from the plume into the building are other surface and subsurface pathways that may be complete at some sites.

At some sites, other routes of exposure may be significant. At sites where these pathways are complete, they must be evaluated under Tier 3 risk assessment. These include exposure due to

(i) ingestion of produce grown in impacted soils,
(ii) exposures associated with use of groundwater for irrigation purposes,
(iii) use of groundwater for industrial purposes, or
(iv) ingestion of fish or other aquatic organisms that have bioaccumulated COCs through the food chain as a result of surface water or sediment contamination.

The resultant Tier 1 risk-based target levels are presented in Appendix B. The Tier 1 risk-based target levels do not account for the presence of other exposure pathways and COCs (additive or cumulative risk).

For Tier 2 risk assessments, the remediating party must calculate the site-specific target levels using technically justifiable, site-specific data. The default fate and transport models used to develop the Tier 1 risk-based target levels must be used. For Tier 3 assessments, site-specific target levels would be calculated using site-specific data and possibly alternative fate and transport models, if approved by the department. Also refer to Table 2-1.

E.2 ACCEPTABLE RISK LEVEL

A risk-based decision making process requires the specification of an acceptable risk level for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, risk is quantified using individual excess lifetime cancer risk (IELCR) and for non-carcinogenic effects, the risk is quantified using a hazard quotient (HQ) or hazard index (HI), which is the sum of hazard quotients when multiple chemicals and multiple exposure pathways are evaluated.

For domestic use of water, maximum contaminant levels (MCLs) are used as the target concentrations at the point of exposure. For COCs that do not have MCLs, the target concentration at the point of exposure (POE) is estimated assuming ingestion of groundwater, dermal contact and indoor inhalation of vapors due to water use under residential conditions.

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Allowable concentrations in surface water depend on the streams' designated beneficial use.

The Tier 1 risk-based target levels are based on acceptable risk levels of 1×10^{-5} for the carcinogenic chemicals and a hazard quotient of 1.0 for non-carcinogenic chemicals. The calculation of risk-based target levels does not account for cumulative site-wide risk. As explained in Section 8.6, these generic target levels may need to be adjusted to account for the cumulative site-wide risk. The acceptable risk levels are as follows:

<u>Carcinogenic Risk</u>

- The total risk for each COC, which is the sum of risk for all complete exposure pathways for each COC, must not exceed 1×10^{-5}.
- The cumulative site-wide risk (sum of risk for all COCs and all complete exposure pathways) must not exceed 1×10^{-4}.

<u>Non-carcinogenic Risk</u>

- The hazard index for each COC, which is the sum of hazard quotients for all complete exposure pathways for each COC must not exceed 1.0.
- The site-wide hazard index, which is the sum of hazard quotients for all COCs and all complete exposure pathways, must not exceed 1.0.

If the hazard index exceeds 1.0, the hazard index corresponding to a specific toxicological end point may be calculated by a qualified toxicologist. In this case, the specific hazard indices for each toxicological end point must be less than unity (1.0).

E.3 QUANTITATIVE TOXICITY FACTORS

Table E-1 gives the toxicity values for the over 300 chemicals (not including the petroleum fractions) considered in the Missouri Risk-Based Corrective Action (MRBCA) process.

Typically, these toxicity values will also be used for Tier 3 risk assessments, although alternate values may be used at Tier 3 with adequate justification and the approval of the department.

The toxicity data was extracted from the hierarchy of sources as per ***"Human Health Toxicity Values in Superfund Risk Assessments," OSWER directive 9285.7-53,***

December 5, 2003. Specifically it included:

1. Tier 1: Integrated Risk Information System (IRIS),
2. Tier 2: Provisional Peer Reviewed Toxicity Values (PPRTVs),
3. Tier 3: Miscellaneous Sources:
   (i) National Center for Environmental Assessment (NCEA) as listed in USEPA's Region IX Preliminary Remediation Goal (PRG) Table,
   (ii) California Office of Environmental Health Hazard Assessments (OEHHAs) chemical database,
   (iii) Health Effects Assessment Summary Tables (HEAST) as listed in USEPA's Region IX PRG tables, and
   (iv) Table for Texas Risk Reduction Program.

Footnotes to Table E-1 indicate the source for each value.

Dermal toxicity values are not available in the above sources; therefore the dermal toxicity values were calculated. The assumption underlying the calculation of dermal toxicity values is that the dermal toxicity of the chemical is the same as the oral toxicity values, except that a semi-permeable barrier (the skin) affects absorption. Using oral toxicity values to calculate dermal toxicity values is based on sound toxicological principles, and in the absence of direct measurement of dermal toxicity, considered an acceptable alternative by the USEPA. However, the calculation is complicated due to the fact that different chemicals pass through the skin with different efficiencies. These differing efficiencies are factored into the formulae for dermal toxicity as the term "oral absorption factors (RAF_o)."

The formulae for calculation of slope factor (SF_d) and reference dose (RfD_d) for dermal exposure are as below:

$$SF_d = \frac{SF_o}{RAF_o} \tag{1}$$

$$RfD_d = RfD_o \times RAF_o \tag{2}$$

where,

SF_o	=	Slope factor for oral exposure (mg/kg-day)$^{-1}$,
RfD_o	=	Reference dose for oral exposure (mg/kg-day)$^{-1}$, and
RAF_o	=	Oral absorption factor (dimensionless).

The oral absorption factors are not readily available. Conservatively, a value of 1.0 was assigned for all chemicals.

The dermal absorption factors were obtained from the ***Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual, Part E Supplemental Guidance for Dermal Risk Assessment*** (USEPA, 2004). However, this guidance does not have any recommendations for volatile organic compounds (VOCs), or inorganic compounds. For these compounds, the absorption factors were obtained from the USEPA Region III and RAGS, Volume 1, Part A.

The parameters used for dermal contact pathway are shown in Table E-2 and are discussed below:

Permeability Coefficient

For organic chemicals, the chemical-specific permeability coefficients in water were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the permeability constant, K_p (cm/hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW \tag{3}$$

where,

K_{ow}	=	Octanol-water partition coefficient (dimensionless), and
MW	=	Molecular weight (g/mole).

Note the MW and K_{ow} are presented in Table E-3.

For metals and inorganics, the permeability coefficients were obtained from Exhibit B-4 of the *RAGS Volume I, Part E* (USEPA, 2004). If no value is available, the permeability coefficient of 1 x 10^{-3} cm/hr is recommended as default value (USEPA, 2004).

Relative Contribution of Permeability Coefficient

The relative contribution of permeability coefficients for the chemicals was obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the relative contribution of permeability coefficient, B (unitless), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$B = K_p \frac{\sqrt{MW}}{2.6} \tag{4}$$

Lag Time

The lag times for the chemicals, τ_{event} (hr/event), were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004).

As per the *RAGS Volume I, Part E* (USEPA, 2004), the equation to estimate τ_{event} is derived as below:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80-0.0056MW)} \tag{5}$$

$$\tau_{event} = \frac{l_{sc}^2}{6 \times D_{sc}} \quad (6)$$

where,

D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr), and
l_{sc}	=	Apparent thickness of stratum corneum (cm).

The lag time is dependent on the effective diffusion coefficient for chemical transfer through the stratum corneum and the apparent thickness of stratum corneum. Assuming $l_{sc} = 10^{-3}$ cm as a default value for the thickness of the stratum corneum, τ_{event} becomes:

$$\tau_{event} = 0.105 \times 10^{(0.0056\,MW)} \quad (7)$$

For chemicals not listed in Exhibit B-3, τ_{event} was estimated using Equation (7).

Equation (7) is based on the assumption that all chemicals absorbed into the skin during the exposure event would eventually be absorbed into the systemic circulation, with the stratum corneum being the main barrier for most chemicals. For highly lipophilic chemicals, the viable epidermis can be a significant barrier for chemical transfer from the stratum corneum to the systemic circulation. When this occurs, the relative rate of desquamation of the stratum corneum and cell proliferation rate at the base of the viable epidermis contribute to a net decrease in the total amount of absorbed chemical. For similar reasons, stratum corneum desquamation can reduce the amount of absorption for chemicals that are not highly lipophilic but large enough that penetration through the stratum corneum is slow.

Time to Reach Steady-State

The time to reach steady-state for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the time to reach steady-state, t^* (hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

If B < 0.6 or B = 0.6,

$$t^* = 2.4\tau_{event} \quad (6)$$

If B > 0.6,

$$t^* = 6\tau_{event} \times \left(b - \sqrt{b^2 - c^2}\right) \quad (7)$$

where b and c are correlation coefficient which have been fitted to the data from Flynn, G.L. (1990) and are expressed as below:

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \text{ and } b = 2 \times \frac{(1 + B)^2}{\pi} - c.$$

Fraction Absorbed Water
The fraction absorbed water for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the fraction absorbed water, *FA* (unitless), was estimated from Exhibit A-5 of the *RAGS Volume I, Part E* (USEPA, 2004).

E.4 PHYSICAL AND CHEMICAL PROPERTIES OF THE COCs

Physical and chemical properties of the COCs are listed in Table E-2. These values must be used for all MRBCA evaluations unless there are justifiable reasons to modify these values and the department approves the alternative values. The use of different values would be allowed only under a Tier 3 risk assessment.

The following hierarchy was used to obtain the physical and chemical properties:
(i) Missouri Department of Natural Resources, Cleanup Levels for Missouri (CALM), (2001) (This MRBCA process replaces CALM),
(ii) USEPA Region IX, PRG's Inter Calc Tables, (2002),
(iii) Texas Commission on Environmental Quality (TCEQ), Texas Risk Reduction Program (TRRP), (2004), and
(iv) Idaho Department of Environmental Quality (IDEQ), RBCA Tables, (2003).

Footnotes on Table E-2 indicate the source for each value.

E.5 EXPOSURE FACTORS

A list of the exposure factors and the values that were used to develop generic Tier 1 risk-based target level values is presented in Table E-3. The exposure factors are typically estimated based on literature rather than site-specific measurements. For a Tier 3 risk assessment, site-specific exposure factors may be used with clear justification and the department's approval. For the evaluation of inhalation exposures, the values of both the exposure time (hours/day) and inhalation rate (cubic meters/day) are significant and interrelated.

A source of exposure factor information is USEPA's ***Exposure Factors Handbook Volume 1 – General Factors*** (August 1997). Other sources of exposure factor data may be used for Tier 3 risk assessment with approval of the department.

E.6 FATE AND TRANSPORT PARAMETERS

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For a Tier 1 risk assessment, the department has selected typical conservative default values that are listed in Table E-4 for three generic vadose zone soil types. These include:

- soil type 1, representative of a sandy soil,
- soil type 2, representative of a silty soil, and
- soil type 3, representative of clayey soil.

See Appendix O for more information on determination of soil types.

For a Tier 2 risk assessment, a combination of site-specific and default fate and transport values may be used. However, the value of each parameter used, whether site-specific or default, <u>must</u> be justified based on site-specific conditions. Where site-specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used.

For a Tier 3 risk assessment, the specific fate and transport parameters required to calculate the target levels would depend on the model used.

E.7 MATHEMATICAL MODELS

The input parameters mentioned above are used in two types of models, or equations, to calculate the risk-based target levels. These are the (i) uptake equations and (ii) fate and transport models. For Tier 1 and Tier 2 risk assessments, the department has selected the models and equations included in this appendix for use.

For Tier 2 risk assessments, the department requires the use of the same equations and models. With the prior approval of the department through the submittal of a Tier 3 work plan, a different set of models may be used for Tier 3 risk assessments.

E.8 TARGET LEVELS FOR PROTECTION OF DOMESTIC USE OF GROUNDWATER

A schematic of the domestic use pathway is shown in Section 6, Figure 6.2. If the groundwater use pathway is deemed to be complete under current or future conditions, it must be quantitatively evaluated as follows:

Step 1: Identify the critical point of exposure (POE). The POE is the nearest down-gradient, three-dimensional location that could reasonably be considered for installation of a groundwater supply well. The POE does not need to be an actual existing well; the POE well could be a hypothetical well. Further the POE may be screened in a deeper uncontaminated zone, and not necessarily a shallow contaminated water bearing zone.

Step 2: Determine target levels at the POE. For COCs that have MCLs, the target level at the POE will be the MCL. For COCs that do not have MCLs, the target levels will be the risk-based calculated value that assumes groundwater ingestion, dermal contact and indoor inhalation of vapors emitted due to water use. Note that the indoor inhalation of vapors based on water use pathway will be considered only for volatile COCs (refer to Figure E-1).

Step 3: Identification of point of demonstration (POD) wells and calculation of target levels at the POD. POD wells are located between the source and the POE to monitor the COC concentrations in groundwater as a means of protecting against exceedances at the POE. Risk-based target concentrations will be developed for the POD using appropriate fate and transport models and site-specific parameters as explained in Section E-12.

Step 4: Calculation of representative soil COC concentrations in the area of release. Risk-based target levels for soil should also be calculated for the area of release using the equations and models presented in this appendix.

This step requires an evaluation of the dilution and attenuation of the COC in the unsaturated zone. For Tier 1 and Tier 2 evaluation, the following depth dependent unsaturated zone dilution attenuation factor (DAF) values were used:

Depth to groundwater less than 20 feet,	DAF = 1
Depth to groundwater 20-50 feet,	DAF = 2
Depth to groundwater >50 feet,	DAF = 4

Thus the quantitative evaluation of this pathway requires the calculation of target levels at the (i) POE, (ii) POD, and (iii) soil source. These concentrations must be compared with representative concentrations for this pathway.

E.9 TARGET LEVELS FOR PROTECTION OF SURFACE WATER BODIES

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Sampling for COCs in surface water bodies will be necessary when COC migration is known or suspected to adversely affect a surface water body.

E.9.1 Protection of Streams

Protection of streams requires the (i) determination of stream classification, (ii) identification of the use designations of the stream, (iii) estimation of allowable COC concentrations in the stream, (iv) determination of stream 7Q10, and (v) calculation of allowable COC concentrations at various locations within the stream and the groundwater plume. The latter include:

- Instream COC concentrations at the instream point of compliance (for example, downstream edge of a mixing zone, if applicable) (C_{sw}),
- Instream COC concentrations at the downstream edge of the zone of initial dilution, if applicable (C_{zid}),
- Groundwater COC concentrations at the point of discharge of the groundwater plume to the surface water body (C_{gw}),

- Groundwater COC concentrations at points of demonstration at different distances between the source and the point of discharge (C_{pod}), and
- Soil COC concentrations at the source area soils (C_{soil}).

The locations of these various points are schematically shown in Figure E-2. Depending on site-specific conditions, sampling for COC concentrations at one or more of these locations may be necessary.

The procedure for protection of streams and surface waters is shown in Figure E-3 and discussed below:

Step 1: Determine stream classification: As per 10 CSR 20-7.031(1)(F), streams in Missouri are classified as Class C, Class P, or P1 waters. Stream classification applies to specific reaches of a stream and not necessarily to the entire stream length. Classification of streams and the length of the classified segment can be found in Table H of 10 CSR 20-7.031. Streams not included in Table H are unclassified (Class U) and have no assigned designated uses.

Step 2: Determine the beneficial use designation(s) of the stream: As per 10 CSR 20-7.031(1)(C), beneficial uses of a stream include one or more of the following:

- Irrigation (IRR),
- Livestock & Wildlife Watering (LWW),
- Protection of Warm Water Aquatic Life and Human Health – Fish Consumption (AQL),
- Cool Water =Fishery (CLF),
- Cold Water Fishery (CDF),
- Whole Body Recreation (WBR),
- Secondary Contact Recreation (SCR)
- Drinking Water Supply (DWS), and
- Industrial (IND).

Beneficial use designations for classified streams are tabulated in Table H of 10 CSR 20-7.031. A stream may have multiple beneficial use designations, in which case all beneficial uses must be identified.

Step 3: Determine stream water quality criteria: Stream water quality criteria depend on the beneficial use designation(s) of the stream and can be found in Table A of 10 CSR 20-7.031. For streams with multiple beneficial uses, select the most protective applicable criteria. For metals, the criteria for the protection of aquatic life depend on the hardness of water. For specific water quality criteria, refer to 10 CSR 20-7.031, Table A.

If COCs for which water quality criteria are not available are present at a site, contact the department's project manager for consultation with the Water Protection Program (WPP).

For Class P and P1 streams, water quality criteria must be met at the downstream edge of the mixing zone. As defined in 10 CSR 20-7.031(1)(P), a mixing zone is "an area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met". For Class C and unclassified streams, applicable water quality criteria must be met at the point of groundwater discharge to the stream.

Step 4: Determine 7Q10 and groundwater discharge: The 7Q10 low-flow of a stream is the average minimum flow for seven consecutive days that has a probable recurrence interval of once-in-ten years. Estimation of 7Q10 must follow current practices as included in USGS and USEPA literature. The lowest value of 7Q10 that can be used as a default value for a Tier 1 risk assessment that includes Class P or P1 streams is 0.1 cubic feet per second (cfs). Class C and unclassified streams have a default 7Q10 value of 0.0 cfs. Also, the volume of impacted groundwater discharging into the stream must be determined. This determination is based on the dimensions of the plume at the point of discharge and an average Darcy velocity at the point of discharge. For flow-regulated streams, contact the department's WPP for the estimation of 7Q10.

Step 5: Estimate concentrations at the groundwater point of discharge: The concentrations at the point of discharge can be estimated using mass balance considerations. For streams with a 7Q10 of 0.1 cfs or greater, the stream flow to be used in the calculation is 0.25 of the 7Q10 flow calculated in Step 4. The specific equations are included in Appendix E, Section E-12.

Step 6: Estimate groundwater and soil concentrations: Applicable COC concentrations for soil and groundwater can be back-calculated using the concept of DAFs. The specific equations, a combination of the Summer and Domenico's models, are presented in Appendix E, Section E-12.

The soil and groundwater COC concentrations discussed above apply to the protection of surface water. Other routes of exposure from groundwater, such as inhalation of volatiles and ingestion of groundwater, must also be evaluated as part of the process. Therefore, cleanup criteria based on these routes of exposure may result in allowable COC concentrations that are lower than those protective of a surface water body.

Step 7:Other considerations: Numeric water quality criteria must be met as per the following:

- For unclassified streams, the acute criteria must be met at the point of discharge,
- For an unclassified stream that flows into a classified stream or becomes a classified stream downstream of the point of discharge, the acute criteria must be met at the point of groundwater discharge to the unclassified stream; chronic criteria must be met at the downstream classified water body.
- For Class C streams, the acute criteria do not apply and chronic criteria must be met in the Class C water body.
- For Class P and P1 streams, the acute criteria must be met at the edge of the zone of initial dilution and throughout the mixing zone; chronic criteria must be met at the downstream edge of the mixing zone.

In addition to numeric water quality criteria, general water quality criteria must be met in waters of the state at all times, including mixing zones. General water quality criteria are discussed in 10 CSR 20-7.031(3).

E.9.2 Protection of Lakes

The above considerations also apply to lakes. However, the mixing zone can not exceed one-quarter (¼) of the lake width at the discharge point or one hundred feet (100 feet) from the discharge point, whichever is less. A zone of initial dilution is not allowed in lakes.

E.10 TARGET LEVELS FOR LEAD

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable from the standpoint of both exposure and toxicity. Certain behaviors, such as crawling and playing on the floor or ground, result in increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overly toxic can result in impaired mental development.

USEPA has developed a model [Integrated Exposure Uptake Biokinetic (IEUBK) Model] to predict the risk of elevated blood lead (PbB) in children under the age of seven who are exposed to environmental lead from various sources. The model predicts the probability that a child exposed to lead concentrations in a specified media will have a PbB level greater than 10 micrograms per deciliter (µg/dL), the level associated with adverse health effects (USEPA, 1999).

Because of the greater vulnerability of children to exposure and toxicity, the primary concern in a residential setting is risk to children. In the non-residential scenario, children are not generally directly exposed, but fetuses carried by female workers can be exposed. The USEPA has developed an adult lead methodology (ALM) to assess risk in this scenario (USEPA, 1996). The methodology is limited in terms of exposure media (soil/dust). Specifically, the methodology estimates the PbB concentrations in fetuses carried by women exposed to lead contaminated soils. Research is ongoing to develop a model capable of simulating multimedia exposures over the entire human lifetime. Until this model is developed, the department will require the use of IEUBK for residential and ALM for non-residential scenarios, if the responsible party chooses to perform a site-specific evaluation for lead and concentrations exceed the following generic levels:

Residential land use soil (direct contact with soil)	260 mg/kg
Non-residential land use soil (direct contact with soil)	660 mg/kg

The above soil concentrations do not account for leaching to groundwater. At sites where this pathway is complete or potentially complete, the department may require a site-specific analysis. Where domestic use of groundwater is a complete pathway, the groundwater target level is 0.015 mg/L.

E.11 TARGET LEVEL CALCULATION FOR LNAPL/DNAPL

The MRBCA process allows for the calculation of risk and target levels when LNAPL or DNAPL is present. Under this condition, the primary routes of exposure are (i) indoor inhalation for a residential or a non-residential receptor, and, (ii) if the domestic use of groundwater pathway is complete or potentially complete, the protection of a current or potential future point of exposure (POE) groundwater well. For these pathways, the key step is the calculation of the vapor concentration and the dissolved concentration emanating from the LNAPL/DNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in Sections E.2 to E.9 above.

<u>Soil Vapor Concentration:</u> The soil vapor concentration in equilibrium with LNAPL/DNAPL is the effective soil vapor concentration. This concentration depends on (i) the chemical-specific saturated soil vapor concentration, and (ii) the mole fraction of the chemical in the LNAPL/DNAPL for which the soil vapor concentration is being calculated. If the mole fraction of a COC is not known, default mole fractions, calculated using the weight fraction of a specific COC in the LNAPL/DNAPL, may be used if the NAPL can be analyzed and its components determined. Alternatively, the evaluator may sample the LNAPL/DNAPL for laboratory analysis to determine site-specific values for the weight and mole fractions. The specific equations used to calculate the effective soil vapor or effective dissolved concentrations are presented in Section E.12.

In the forward model of risk assessment, the effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration in the point of demonstration (POD) and POE wells. If DNAPL is located below the water table, pathways related to inhalation of vapors generated from the DNAPL will be considered incomplete, as vapors will not penetrate the overlying column of saturated soil.

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E.12 MODELS/EQUATIONS FOR ESTIMATING DTLs AND TIER 1 AND 2 RISK-BASED TARGET LEVELS WITHIN THE MRBCA PROCESS

INDOOR INHALATION OF VAPORS
(CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)

Carcinogenic effects

$$RBTL_{ai} = \frac{TR \times BW \times AT_c \times 365}{IR_{ai} \times ET_{in} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ET_{in} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

$RBTL_{ai}$	=	Risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
IR_{ai}	=	Indoor inhalation rate [m^3/hr]
ET_{in}	=	Indoor exposure time [hr/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

OUTDOOR INHALATION OF VAPORS (CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{ao} = \frac{TR \times BW \times AT_c \times 365}{IR_{ao} \times ET_{out} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ao} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ET_{out} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

$RBTL_{ao}$	=	Risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor exposure time [hr/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

DERMAL CONTACT WITH CHEMICALS IN WATER
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{dw} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

Non-carcinogenic effects

$$RBTL_{dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_d}{SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

For organic chemicals,

If $t_{event} \leq t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$

If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z = K_p \times t_{event}$

where:

$RBTL_{dw}$	= Risk-based target level for dermal contact with groundwater [mg/L]
TR	= Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	= Target hazard quotient for individual constituents [-]
BW	= Body weight [kg]
AT_c	= Averaging time for carcinogens[year]
AT_{nc}	= Averaging time for non-carcinogens[year]
SA_{gw}	= Skin surface area available for contact with water [cm^2]
EV_{gw}	= Event frequency [event/day]
ED	= Exposure duration [year]
EF	= Exposure frequency [day/year]
RfD_d	= Chemical-specific dermal reference dose [mg/kg-day]
SF_d	= Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$
365	= Converts AT_c, AT_{nc} in years to days [day/year]
1000	= Conversion factor from cm^3 to L [cm^3/L]
t_{event}	= Event duration [hr/event]
t^*	= Chemical-specific time to reach steady-state [hr]
Z	= Chemical-specific dermal factor [cm/event]
K_p	= Chemical-specific dermal permeability coefficient [cm/hr]
FA	= Chemical-specific fraction absorbed in water [-]
τ_{event}	= Chemical-specific lag time [hr/event]
B	= Chemical-specific relative contribution of permeability coefficient [-]

$B = K_P \frac{\sqrt{MW}}{2.6}$ $\log K_P = -2.80 + 0.66 \log K_{OW} - 0.0056 MW$ If B<0.6 or B=0.6, then, $t^* = 2.4\tau_{event}$ If B>0.6 then, $t^* = 6\tau_{event} \times (b - \sqrt{b^2 - c^2})$ where, $c = \frac{1 + 3B + 3B^2}{3(1+B)}$ $b = 2 \times \frac{(1+B)^2}{\pi} - c$ $\tau_{event} = 0.105 \times 10^{(0.0056 MW)}$ Source: Modified from RAGS, Vol. I, Part E, 2004.	where: *MW* = Molecular weight [g/mole] K_{ow} = Octanol water partition coefficient [L/kg] *b, c* = Correlation coefficient which have been fitted to the data from Flynn, G.L. (1990)

DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times \left[\left(SF_o \times IR_w \right) + \left(SF_i \times ET \times K_f \times IR_a \right) + \left(\frac{SF_d}{1000} \times SA_{wb} \times EV_{wb} \times Z_{wb} \right) \right]}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w \right) + \left(\frac{1}{RfD_i} \times K_f \times ET \times IR_a \right) + \left(\frac{SA_{wb} \times EV_{wb} \times Z_{wb}}{RfD_d \times 1000} \right) \right]}$$

For organic chemicals,

If $t_{wb\text{-}event} \leq t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: $K_f = 0$ for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10^{-4} or Henry's law constant (atm-m^3/mol) <1.5 x 10^{-5}).

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
IR_w	=	Water ingestion rate [L/day]
IR_a	=	Indoor inhalation rate [m^3/hr]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
K_f	=	Volatilization factor [L/m^3]
ET	=	Exposure time [hr/day]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
SF_i	=	Chemical-specific inhalation cancer slope or potency factor $[(mg/kg\text{-}day)^{-1}]$
SF_d	=	Chemical-specific dermal cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

DERMAL CONTACT WITH CHEMICALS IN SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{dcss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Non-carcinogenic effects

$$RBTL_{dcss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_d}{EF \times ED \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcss}$	=	Risk-based target level for dermal contact of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
SA_{soil}	=	Skin surface area available for contact with soil [cm^2]
EV_{soil}	=	Event frequency [event/day]
AF	=	Soil to skin adherence factor [mg/cm^2-event]
RAF_d	=	Chemical-specific dermal relative absorption factor [-]
SF_d	=	Dermal cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
RfD_d	=	Chemical-specific oral reference dose [mg/kg-day]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)	
<u>Carcinogenic effects</u> $$RBTL_{ingss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_o \times 10^{-6} \times IR_{soil} \times RAF_o}$$ <u>Non-carcinogenic effects</u> $$RBTL_{ingss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF \times ED \times 10^{-6} \times IR_{soil} \times RAF_o}$$	where: $RBTL_{ingss}$ = Risk-based target level for ingestion of chemicals in surficial soil [mg/kg] TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-] THQ = Target hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] IR_{soil} = Soil ingestion rate [mg/day] RAF_o = Oral relative absorption factor [-] SF_o = Oral cancer slope factor [(mg/kg-day)$^{-1}$] *365* = Converts AT_c, AT_{nc} in years to days [day/year]

INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

<u>Carcinogenic effects</u>

$$RBTL_{inhss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_i \times IR_{ao} \times ET_{out} \times (VF_{SS} + VF_p)}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{inhss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{EF \times ED \times ET_{out} \times IR_{ao} \times (VF_{ss} + VF_p)}$$

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10^{-4} or Henry's law constant (atm-m^3/mol) <1.5 x 10^{-5}).

where:

$RBTL_{inhss}$	=	Risk-based target level of inhalation of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor exposure time [hr/day]
SF_i	=	Inhalation cancer slope factor [(mg/kg-day)$^{-1}$]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-day]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

Note: The depth to surficial soil for a construction worker is up to the typical construction depth.

INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{ss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times \left[\left(SF_o \times 10^{-6} \times IR_{soil} \times RAF_o\right) + \left(SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d\right) + \left(SF_i \times IR_{ao} \times ET_{out} \times \left(VF_{ss} + VF_p\right)\right)\right]}$$

Non-carcinogenic effects

$$RBTL_{ss} = \frac{THQ \times BW \times AT_{nc} \times 365}{EF \times ED \times \left[\frac{10^{-6} \times IR_{soil} \times RAF_o}{RfD_o} + \frac{10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}{RfD_d} + \frac{ET_{out} \times IR_{ao} \times \left(VF_{ss} + VF_p\right)}{RfD_i}\right]}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{ss}$	=	Risk-based target level of surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{soil}	=	Soil ingestion rate [mg/day]
RAF_o	=	Oral relative absorption factor [-]
SA	=	Skin surface area [cm^2/day]
EV_{soil}	=	Event frequency [event/day]
AF	=	Soil to skin adherence factor [mg/cm^2]
RAF_d	=	Dermal relative adsorption factor [-]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor exposure time [hr/day]
SF_o	=	Oral cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
SF_i	=	Inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
RfD_o	=	The chemical-specific oral reference dose [mg/kg-day]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-day]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ai-aa} \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ai-aa}}$$

where:

$$IR_{ai-aa} = \frac{IR_{ai-c} \times ED_c \times EF_c \times ET_{i-c}}{BW_c} + \frac{IR_{ai-a} \times ED_a \times EF_a \times ET_{i-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B, 1991

where:

$RBTL_{ai\text{-}adj}$	=	Age-adjusted risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
$IR_{ai\text{-}aa}$	=	Age-adjusted indoor inhalation rate [m^3/ kg]
$IR_{ai\text{-}c}$	=	Resident child indoor inhalation rate [m^3/hr]
$IR_{ai\text{-}a}$	=	Resident adult indoor inhalation rate [m^3/hr]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
$ET_{i\text{-}c}$	=	Indoor exposure time for a child [hour/day]
$ET_{i\text{-}a}$	=	Indoor exposure time for an adult [hour/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [mg/kg-day]$^{-1}$
365	=	Conversion factor [day/year]

DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{TR \times AT_c \times 365 \times 1000}{SF_d \times \left(DC_{w-c} \times Z_c + DC_{w-a} \times Z_a\right)}$$

Non-carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times 1000 \times RfD_d}{DC_{w-c} \times Z_c + DC_{w-a} \times Z_a}$$

where :

$$DC_{w\text{-}c} = \frac{ED_c \times EF_c \times SA_{gw-c} \times EV_{gw-c}}{BW_c}$$

$$DC_{w\text{-}a} = \frac{ED_a \times EF_a \times SA_{gw-a} \times EV_{gw-a}}{BW_a}$$

For organic chemicals,

If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$

If $t_{event} > t^*$, then

$$Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event}\left(\frac{1+3B+3B^2}{(1+B)^2}\right)\right]$$

For inorganic chemicals, $Z = K_p \times t_{event}$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcw\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with chemicals in groundwater [mg/L-water]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day) $^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
t_{event}	=	Event duration [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]
$DC_{w\text{-}c}$	=	Child dermal contact rate with groundwater [cm^2-event/kg]
$DC_{w\text{-}a}$	=	Adult dermal contact rate with groundwater [cm^2-event/kg]
$EV_{gw\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{gw\text{-}a}$	=	Resident adult event frequency [event/day]
Z_c	=	Resident child chemical-specific dermal factor [cm/event]
Z_a	=	Resident adult chemical-specific dermal factor [cm/event]
$SA_{gw\text{-}c}$	=	Resident child skin surface area available for contact with water [cm^2]
$SA_{gw\text{-}a}$	=	Resident adult skin surface area available for contact with water [cm^2]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]

DOMESTIC WATER USE (AGE-ADJUSTED RESIDENT)
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)

Carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{TR \times AT_c \times 365}{\left[\left(SF_o \times IR_{w\text{-}aa}\right) + \left(SF_i \times K_f \times IR_{a\text{-}aa}\right) + \left(\frac{SF_d}{1000} \times \left(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a} \right) \right) \right]}$$

Non-carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{THQ \times AT_{nc} \times 365}{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa} \right) + \left(\frac{1}{RfD_i} \times K_f \times IR_{a-aa} \right) + \left(\frac{\left(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a} \right)}{RfD_d \times 1000} \right) \right]}$$

where:

$$IR_{w\text{-}aa} = \frac{ED_c \times EF_c \times IR_{w-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{w-a}}{BW_a}$$

$$IR_{a\text{-}aa} = \frac{ED_c \times EF_c \times ET_c \times IR_{a-c}}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times IR_{a-a}}{BW_a}$$

$$DC_{wb\text{-}c} = \frac{ED_c \times EF_c \times SA_{wb-c} \times EV_{wb-c}}{BW_c}$$ and $$DC_{wb\text{-}a} = \frac{ED_a \times EF_a \times SA_{wb-a} \times EV_{wb-a}}{BW_a}$$

For organic chemicals,

If $t_{wb\text{-}event} \leq t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: $K_f = 0$ for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10^{-4} or Henry's law constant (atm-m^3/mol) <1.5 x 10^{-5}).
Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{w\text{-}adj}$	=	Age-adjusted risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day) $^{-1}$]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day) $^{-1}$]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident child groundwater ingestion rate [L/day]
$IR_{a\text{-}c}$	=	Resident child inhalation rate [m^3/hr]
$IR_{w\text{-}a}$	=	Resident adult groundwater ingestion rate [L/day]

$IR_{a\text{-}a}$	=	Resident adult inhalation rate [m^3/hr]
$DC_{wb\text{-}c}$	=	Child dermal whole-body contact rate with groundwater [cm^2-event/kg]
$DC_{wb\text{-}a}$	=	Adult dermal whole-body contact rate with groundwater [cm^2-event/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ET_c	=	Resident child exposure time [hr/day]
ET_a	=	Resident adult exposure time [hr/day]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
K_f	=	Volatilization factor [L/m^3]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
365	=	Conversion factor [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{dcss\text{-}adj} = \frac{TR \times AT_c \times 365}{SF_d \times SA_{soil-aa} \times RAF_d \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{dcss\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_d}{SA_{soil-aa} \times RAF_d \times 10^{-6}}$$

where:

$$SA_{soil-aa} = \frac{ED_c \times EF_c \times AF_c \times SA_{soil-c} \times EV_{soil-c}}{BW_c} + \frac{ED_a \times EF_a \times AF_a \times SA_{soil-a} \times EV_{soil-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcss\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
RAF_d	=	Dermal relative absorption factor [-]
AF_c	=	Resident child soil to skin adherence factor [mg/cm^2-event]
AF_a	=	Resident adult soil to skin adherence factor [mg/cm^2-event]
RfD_d	=	Chemical-specific dermal reference dose [(mg/kg-day)]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day)$^{-1}$]
SA_{aa}	=	Age-adjusted skin surface area [mg/ kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
$SA_{soil\text{-}c}$	=	Resident child skin surface area available for contact with soil [cm^2/day]
$SA_{soil\text{-}a}$	=	Resident adult skin surface area available for contact with soil [cm^2/day]
$EV_{soil\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{soil\text{-}a}$	=	Resident Child event frequency [event/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ingss-adj} = \frac{TR \times AT_c \times 365}{SF_o \times IR_{s-aa} \times RAF_o \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{ingss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{IR_{s-aa} \times RAF_o \times 10^{-6}}$$

where :

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

where:

$RBTL_{ingss\text{-}adj}$	=	Risk-based target level for ingestion of soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RAF_o	=	Oral relative absorption factor [-]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day) $^{-1}$]
$IR_{s\text{-}aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s\text{-}c}$	=	Resident child soil ingestion rate [mg/day]
$IR_{s\text{-}a}$	=	Resident adult soil ingestion rate [mg/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ss-adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i \times \left(VF_{ss} + VF_p\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

where:

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2×10^{-4} or Henry's law constant (atm-m^3/mol) <1.5×10^{-5}).

Source: Modified from RAGS, Vol. I, Part B, 1991

where:

$RBTL_{ss\text{-}adj}$	=	Age-adjusted risk-based target level in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil[kg-soil/m^3-air]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]
$IR_{ao\text{-}aa}$	=	Age-adjusted outdoor inhalation rate [m^3/kg]
$IR_{ao\text{-}c}$	=	Resident child outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}a}$	=	Resident adult outdoor inhalation rate [m^3/hr]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o\text{-}a}$	=	Outdoor exposure time for an adult [hour/day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
365	=	Conversion factor [day/year]

INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ss-combined} = \frac{TR \times AT_c \times 365}{\left(SF_o \times 10^{-6} \times IR_{s-aa} \times RAF_o\right) + \left(SF_d \times 10^{-6} \times SA_{soil-aa} \times RAF_d\right) + SF_i \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

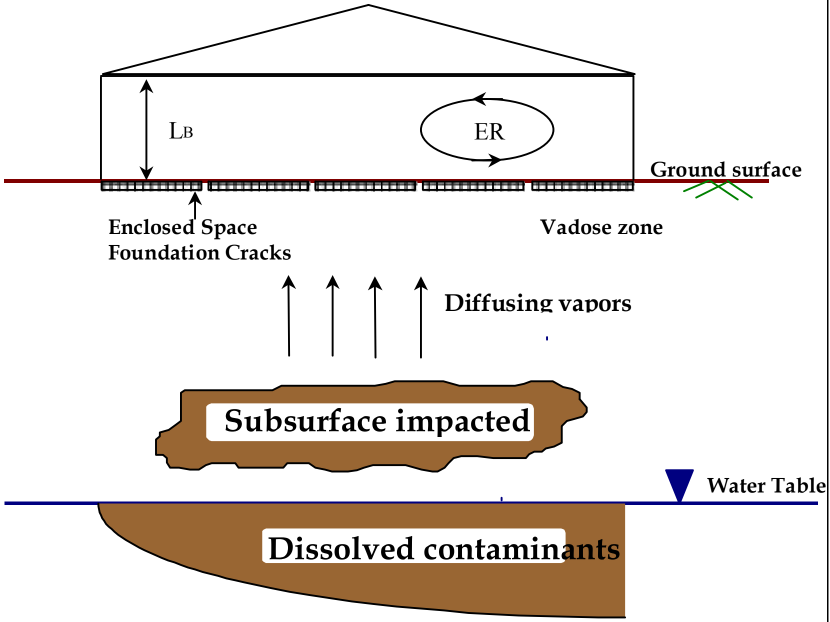
Non-carcinogenic effects

$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times IR_{s-aa} \times RAF_o + \frac{1}{RfD_d} \times 10^{-6} \times SA_{soil-aa} \times RAF_d + \frac{1}{RfD_i} \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Note: All parameters are defined under the individual pathway equations.

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2×10^{-4} or Henry's law constant (atm-m^3/mol) < 1.5×10^{-5}).

Source: Modified from RAGS, Vol. I, Part E, 2004.

SUBSURFACE SOIL VAPOR CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION	
	$$RBTL_{svi} = \frac{RBTL_{ai}}{VF_{sv}}$$ where: $RBTL_{svi}$ = Risk-based target level for indoor inhalation of vapors from subsurface [mg/m^3-air] $RBTL_{ai}$ = Risk-based target level for indoor inhalation of air [mg/m^3-air] VF_{sv} = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-] Source: ASTM E1739-95

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{VF_{sesp}}$$

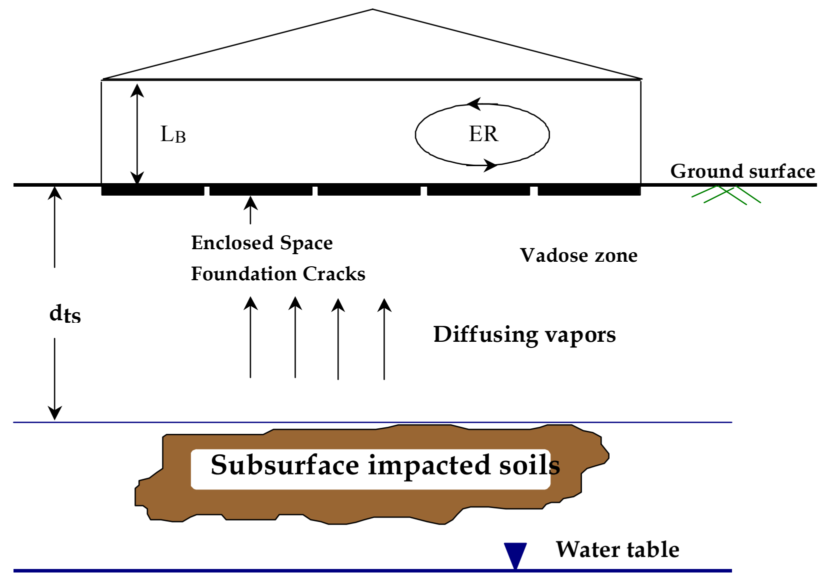
where:

$RBTL_{si}$ = Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg-soil]

$RBTL_{ai}$ = Risk-based target level for indoor inhalation of air [mg/m^3-air]

VF_{sesp} = Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]

Source: ASTM E1739-95



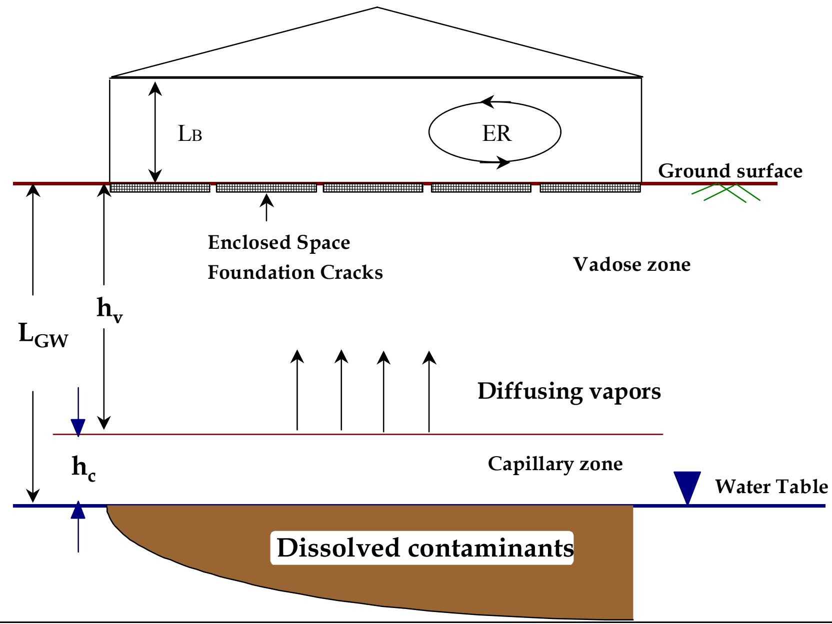
GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{VF_{wesp}}$$

where:

$RBTL_{wi}$	=	Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air (mg/m^3-air)
VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-water)]

Source: ASTM E1739-95



GROUNDWATER CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ao}}{VF_{wamb}}$$

where:

$RBTL_{wi}$	=	Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]
$RBTL_{ao}$	=	Risk-based target level for outdoor inhalation of air (mg/m^3-air)
VF_{wamb}	=	Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)]

Source: ASTM E1739-95

VOLATILIZATION FACTORS
(SURFICIAL SOIL TO OUTDOOR AIR)

$$VF_{ss} = \left[Q/C \times \frac{\left(3.14 \times D_A \times \tau\right)^{1/2}}{\left(2 \times \rho_s \times D_A\right)} \times 10^{-4} \right]^{-1}$$

where:

$$D_A = \frac{\left(\theta_{as}^{10/3} \times D^a \times H + \theta_{ws}^{10/3} \times D^w\right) / \theta_T^2}{\rho_s \times K_{sv} + \theta_{ws} + \theta_{as} \times H}$$

or

$$VF_{ss} = \frac{W_a \times \rho_s \times d_s}{U_m \times \delta_a \times \tau} \times 10^3$$

Use smaller of the two VF_{ss}.

Source: Soil Screening Guidance, 1996

where:

VF_{ss}	=	Volatilization factor from surficial soil to outdoor (ambient) air [kg-soil/m^3-air]
Q/C	=	Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
D_A	=	Apparent diffusivity [cm^2/s]
τ	=	Averaging time for vapor flux [s]
ρ_s	=	Vadose zone dry soil bulk density of surficial soil [g-soil/cm^3-soil]
K_{sv}	=	Chemical-specific solid-water sorption coefficient [cm^3-water/g-soil]
D_a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D_w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_T	=	Total soil porosity in the surficial soils [cm^3/cm^3-soil]
θ_{as}	=	Volumetric air content in the surficial soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in the surficial soils [cm^3-water/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(L-water)/(L-air)]
10^{-4}	=	Conversion factor [m^2/cm^2]
W_a	=	Dimension of soil source area parallel to wind direction [cm]
d_s	=	Depth to base of surficial soil zone [cm]
U_m	=	Mean annual wind speed [m/s]
δ_a	=	Breathing zone height [cm]
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

Note: Surficial soil properties are assumed same as the vadose zone properties.

VOLATILIZATION FACTORS
(PARTICULAR EMISSIONS FROM SURFICIAL SOIL)

$$VF_p = \left[Q/C \times \frac{3600}{0.036 \times (1 - V) \times \left(U_m / U_t\right)^3 \times F(x)} \right]^{-1}$$

Source: Soil Screening Guidance, 1996

where:

VF_p	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]
Q/C	=	Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
V	=	Fraction of vegetative cover [-]
U_m	=	Mean annual wind speed [m/s]
U_t	=	Equivalent threshold value of wind speed at 7 m [m/s]
$F(x)$	=	Function dependent on U_m/U_t derived using Cowherd *et al.* 1985 [-]
0.036	=	Empirical constant [g/m^2-hr]

VOLATILIZATION FACTORS (SUBSURFACE SOIL VAPOR TO INDOOR AIR)	
$$VF_{sv} = \frac{\left[\frac{D_s^{eff}/d_{sv}}{ER \times L_B}\right]}{1 + \left[\frac{D_s^{eff}/d_{sv}}{ER \times L_B}\right] + \left[\frac{D_s^{eff}/d_{sv}}{\left(D_{crack}^{eff}/L_{crack}\right) \times \eta}\right]}$$ Source: ASTM E1739-95	where: VF_{sv} = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-water/cm^3-soil] θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil d_{sv} = Depth to subsurface soil vapor samples taken [cm] L_B = Enclosed space volume/infiltration area ratio [cm] L_{crack} = Enclosed space foundation or wall thickness [cm] ER = Enclosed space air exchange rate [1/s] $D^{eff}{}_s$ = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] $D^{eff}{}_{crack}$ = Effective diffusion coefficient through foundation cracks [cm^2/s] η = Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]

VOLATILIZATION FACTORS
(SUBSURFACE SOIL TO INDOOR AIR)

$$VF_{sesp} = \frac{\dfrac{H \times \rho_s}{[\theta_{ws} + (K_{sv} \times \rho_s) + (H \times \theta_{as})]} \times \left[\dfrac{D_s^{eff} / d_{ts}}{ER \times L_B}\right]}{1 + \left[\dfrac{D_s^{eff} / d_{ts}}{ER \times L_B}\right] + \left[\dfrac{D_s^{eff} / d_{ts}}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta}\right]} \times 10^3$$

Source: ASTM E1739-95

where:

VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [m^3-air/(mg/kg-soil)]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]
ρ_s	=	Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-water/cm^3-soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$
	=	Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-water/g-soil]
θ_{as}	=	Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil
d_{ts}	=	Depth to subsurface soil sources [cm]
L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
D^{eff}_s	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
D^{eff}_{crack}	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

VOLATILIZATION FACTORS
(GROUNDWATER TO INDOOR AIR)

$$VF_{wesp} = \frac{H \times \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right]}{1 + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right] + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{\left(D_{crack}^{eff} / L_{crack} \right) \times \eta} \right]} \times 10^3$$

Source: ASTM E1739-95

where:

VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-water)]
H	=	Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)]
L_{GW}	=	Depth to groundwater [cm]
L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
$D^{eff}{}_{ws}$	=	Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
$D^{eff}{}_{crack}$	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [L/m^3]

VOLATILIZATION FACTORS (GROUNDWATER TO OUTDOOR AIR)	
$$VF_{wamb} = \frac{H}{1 + \left(\frac{100 \times U_m \times \delta_a \times L_{GW}}{W_{ga} \times D_{ws}^{eff}} \right)} \times 10^3$$ Source: ASTM E1739-95	where: VF_{wamb} = Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)] H = Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)] U_m = Mean annual wind speed [m/s] δ_a = Breathing zone height [cm] L_{GW} = Depth to groundwater [cm] D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s] W_{ga} = Dimension of soil source area parallel to wind direction [cm] 100 = Conversion factor [cm/m] 10^3 = Conversion factor [L/m^3]

EFFECTIVE DIFFUSION COEFFICIENTS

D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

$$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as}	=	Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-water/cm^3-soil]
θ_T	=	Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]

D_{ws}^{eff} : effective diffusion coefficient between groundwater and surface soil [cm^2/s]

$$D_{ws}^{eff} = (h_{cap} + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$

where:

h_{cap}	=	Thickness of capillary fringe [cm]
h_v	=	Thickness of vadose zone [cm]
D_{cap}^{eff}	=	Effective diffusion coefficient through capillary fringe [cm^2/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
L_{GW}	=	Depth to groundwater (h_{cap} + h_v) [cm]

D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s]

$$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^2}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acap}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{wcap}	=	Volumetric water content in capillary fringe soils [cm^3-water/cm^3-soil]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]

D_{crack}^{eff} : effective diffusion coeff. through foundation cracks [cm^2/s]

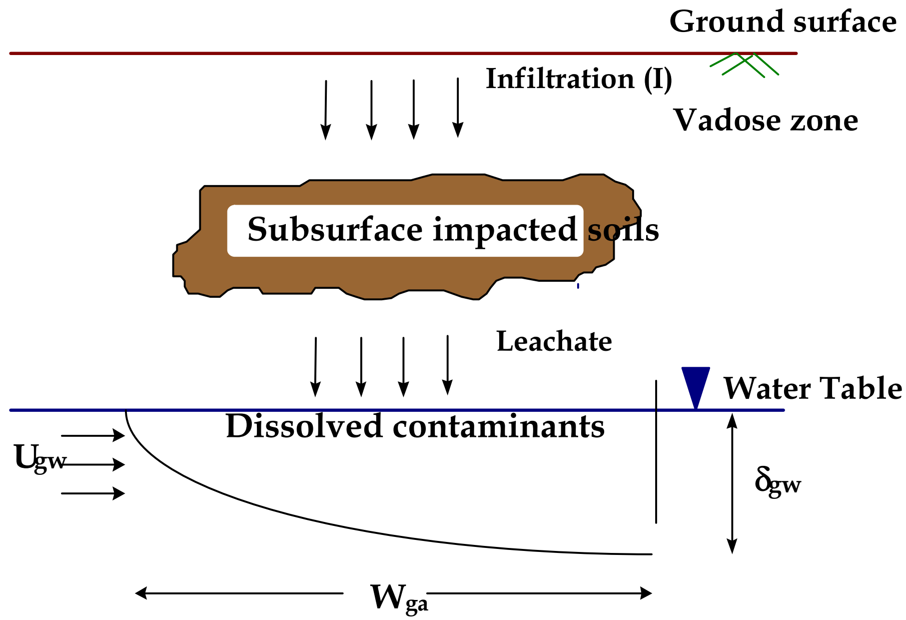
$$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acrack}	=	Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume]
θ_{wcrack}	=	Volumetric water content in foundation/wall cracks [cm^3-water/cm^3-total volume]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]

Source: ASTM E1739-95

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER



$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

where:

$RBTL_{SL}$	=	Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]
$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-water]
LF_{SW}	=	Leaching Factor (from subsurface soil to groundwater) [(mg/L-water)/(mg/kg-soil)]

Source: ASTM E1739-95

LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

$$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_{sv} \times \rho_s + H \times \theta_{as}] \times \left(1 + \frac{U_{gw} \times \delta_{gw}}{I \times W_{ga}}\right)}$$

where:

LF_{SW}	=	Leaching factor from subsurface soil to groundwater [(mg/L-water)/(mg/kg-soil)]
ρ_s	=	Vadose zone dry soil bulk density [g-soil/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-water/cm^3- soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-water/g-soil]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw}	=	Ki = Groundwater Darcy velocity [cm/yr]
K	=	Hydraulic conductivity of the saturated zone [cm/year]
i	=	Hydraulic gradient in the saturated zone [-]
δ_{gw}	=	Groundwater mixing zone thickness [cm]
I	=	Infiltration rate of water through vadose zone [cm/year]
W_{ga}	=	Groundwater dimension parallel to groundwater flow direction [cm]

This equation consists of two parts (i) the Summer's model and (ii) equilibrium conversion of the leachate concentration to a soil concentration on a dry weight basis.

Source: ASTM E1739-95

SOIL CONCENTRATION AT WHICH DISSOLVED PORE WATER AND VAPOR PHASES BECOME SATURATED

Single Component

$$C_s^{SAT} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

Multiple Components

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

where:

C_s^{SAT} = Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
S = Pure component solubility in water [mg/L-water]
S_{ei} = Effective solubility of component i in water = $x_i \times S$ [mg/L-water]
x_i = Mole fraction of component $i = (w_i \times MW_{avg})/MW_i$ [-]
w_i = Weight fraction of component i [-]
MW_{avg} = Average molecular weight of mixture [g/mole]
MW_i = Molecular weight of component i [g/mole]
ρ_s = Vadose zone dry soil bulk density [g-soil/cm^3-soil]
H = Chemical-specific Henry's Law constant [L-water/L-air]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-water/cm^3- soil]
K_{sv} = $f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-water/g-soil]
f_{ocv} = Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM E1739-95

SOIL VAPOR CONCENTRATION AT WHICH VAPOR PHASE BECOMES SATURATED

Single Component

$$C_v^{SAT} = \frac{P^s \times MW}{R \times T} \times 10^6$$

Multiple Components

$$C_v^{SAT} = \frac{x_i \times P_i^s \times MW_i}{R \times T} \times 10^6$$

where:

C_v^{SAT}	=	Soil vapor concentration at which vapor phase become saturated [mg/m^3-air]
P^s	=	Saturated vapor pressure [atm]
P_i^s	=	Effective vapor pressure of component i in water = $x_i \times P^s$ [atm]
R	=	Ideal gas constant [0.08206 atm•L/mol•K]
T	=	Temperature [K]
S_{ei}	=	Effective solubility of component i in water = $x_i \times S$ [mg/L-water]
x_i	=	Mole fraction of component $i = (w_i \times MW_{avg})/MW_i$ [-]
w_i	=	Weight fraction of component i [-]
MW_{avg}	=	Average molecular weight of mixture [g/mole]
MW_i	=	Molecular weight of component i [g/mole]
ρ_s	=	Vadose zone dry soil bulk density [g-soil/cm^3-soil]
10^6	=	Conversion factor [(g/L)/(mg/m^3)]

Source: ASTM E1739-95

DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\,\alpha_x}\left[1 - \sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right] \times erfc\left[\frac{\left[(x - vt)\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]}{2\sqrt{\alpha_x \times v \times t}}\right] \times$$

$$\left[erf\left[\frac{(y+Y/2)}{2\sqrt{\alpha_y\,x}}\right] - erf\left[\frac{(y-Y/2)}{2\sqrt{\alpha_y\,x}}\right]\right] \times \left[erf\left[\frac{(z+Z)}{2\sqrt{\alpha_z\,x}}\right] - erf\left[\frac{(z-Z)}{2\sqrt{\alpha_z\,x}}\right]\right]$$

where:

C	=	Dissolved-phase concentration [mg/L]
C_o	=	Dissolved-phase concentration at the source (at x=y=z=0) [mg/L]
v	=	Retarded seepage velocity [m/sec]
λ	=	Overall first order bio-decay rate [1/day]
α_x	=	Longitudinal dispersivity [m]
α_y	=	Lateral dispersivity [m]
α_z	=	Vertical dispersivity [m]
x, y, z	=	Spatial coordinates [m]
t	=	Time [day]
x	=	Distance along the centerline measured from the downgradient edge of the groundwater source [m]
Y	=	GW source dimension perpendicular to GW flow direction [m]
Z	=	GW source (mixing zone) thickness [m]
DA F_{sat}	=	$C_o/C(x)$

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\,\alpha_x}\left[1 - \sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right] \times erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right] \times erf\left[\frac{Z}{2\sqrt{\alpha_z\,x}}\right]$$

At the centerline, for steady-state the concentration without decay can be obtained by setting y = 0, z = 0, x << vt, and $\lambda = 0$ as:

$$\frac{C(x)}{C_o} = erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right] \times erf\left[\frac{Z}{2\sqrt{\alpha_z\,x}}\right]$$

Note: Compare to ASTM E1739-95, p. 31, where $Y = S_w$ $Z = S_d$, $v = u$, and $C_o = C_{source}$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration at POE is expressed in mg/L-water. Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate [1/day]} = \frac{0.693}{Half\ \ Life}; \quad v = \frac{Ki}{\theta_{TS} R_s}$$

$$\text{Retardation factor for organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right), \quad K_{ss} = f_{ocs} \times K_{oc} \text{ (for organics only)}$$

where:

v	=	Regarded seepage velocity [cm/year]
K	=	Hydraulic conductivity in saturated zone [cm/year]
i	=	Hydraulic gradient in saturated zone [-]
ρ_{ss}	=	Saturated zone dry soil bulk density [g-soil/cm^3-soil]
K_{ss}	=	Chemical-specific soil-water sorption coefficient in the saturated zone [cm^3-water/g-soil]
K_{oc}	=	Chemical-specific normalized partition coefficient [cm^3/g-C]
θ_{TS}	=	Total porosity in the saturated zone [cm^3/g-C]
f_{ocs}	=	Fractional organic carbon content in the saturated zone [g-C/g-soil]

ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION FOR RESIDENT AND NON-RESIDENTIAL WORKER

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{DAF_{POD}}$$

where:

POD	=	Point of demonstration
DAF_{bldg}	=	Dilution attenuation factor between the on/off-site building and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration below on/off-site building is expressed in mg/L-water

STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

$$C_{gw} = \frac{C_{sw}\left(Q_{gw} + Q_{sw}\right)}{Q_{gw}} - C_{su}\left(\frac{Q_{sw}}{Q_{gw}}\right)$$

$$Q_{gw} = \left(Z + \sqrt{\alpha_z X_s}\right) \times \left(Y + 2\sqrt{\alpha_y X_s}\right) \times U_{gw}$$

where:

Q_{gw}	=	Impacted groundwater discharge into the stream [ft^3/day]
C_{gw}	=	Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
Q_{sw}	=	Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft^3/day]
C_{sw}	=	Allowable concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
C_{su}	=	The COCs' concentration upstream of the groundwater plume discharge [mg/L]
Y	=	GW source dimension perpendicular to GW flow direction [ft]
Z	=	GW source (mixing zone) thickness [ft]
α_y	=	Lateral dispersivity [ft]
α_z	=	Vertical dispersivity [ft]
X_s	=	Distance from the downgradient edge of the groundwater source to the stream [ft]
U_{gw}	=	Darcy velocity [ft/day]

STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POD

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and the source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

For calculation of DAF_{POE} and DAF_{POD}, please refer to Domenico's model.

APPENDIX E
TABLES E-1, E-2 AND E-3

Appendix E, Tables E-1 (Toxicity Values of Chemicals), E-2 (Parameters for Dermal Contact Pathway), and E-3 (Physical and Chemical Properties of Chemicals) have been updated. Therefore, because of their size, these tables have been removed from this April 2006 version. The revised Tables are available on the MRBCA web page.

Table E-4
Exposure Factors

Parameter	Symbol	Unit	Default
Averaging Time for Carcinogen	AT_c	year	70
Averaging Time for Non-Carcinogen	AT_{nc}	year	=ED
Body Weight:			
Resident Child	BW	kg	15
Resident Adult	BW	kg	70
Non-Residential Worker	BW	kg	70
Construction Worker	BW	kg	70
Exposure Duration:			
Resident Child	ED	year	6
Resident Adult	ED	year	24
Non-Residential Worker	ED	year	25
Construction Worker	ED	year	1
Exposure Frequency:			
Resident Child	EF	day/year	350
Resident Adult	EF	day/year	350
Non-Residential Worker	EF	day/year	250
Construction Worker	EF	day/year	90
Soil Ingestion Rate:			
Resident Child	IR_{soil}	mg/day	200
Resident Adult	IR_{soil}	mg/day	100
Non-Residential Worker	IR_{soil}	mg/day	100
Construction Worker	IR_{soil}	mg/day	100
Groundwater Ingestion Rate:			
Resident Child	IR^{w}	L/day	1
Resident Adult	IR^{w}	L/day	2
Indoor Inhalation Rate (hourly):			
Resident Child	IRai	m^3/hr	0.416
Resident Adult	IRai	m^3/hr	0.833
Non-Residential Worker	IRai	m^3/hr	0.833
Exposure Time for Indoor Inhalation:			
Resident Child	ET_{in}	hr/day	18
Resident Adult	ET_{in}	hr/day	18
Non-Residential Worker	ET_{in}	hr/day	18
Indoor Inhalation Rate (daily)*:			
Resident Child	IR_a	m^3/day	7.5
Resident Adult	IR_a	m^3/day	15.0
Non-Residential Worker	IR_a	m^3/day	15.0
Outdoor Inhalation Rate (hourly):			
Resident Child	IR_{ao}	m^3/hr	0.416
Resident Adult	IR_{ao}	m^3/hr	0.833
Non-Residential Worker	IR_{ao}	m^3/hr	0.833
Construction Worker	IR_{ao}	m^3/hr	1.62

Table E-4
Exposure Factors

Parameter	Symbol	Unit	Default
Exposure Time for Outdoor Inhalation:			
Resident Child	ET_{out}	hr/day	6
Resident Adult	ET_{out}	hr/day	6
Non-Residential Worker	ET_{out}	hr/day	6
Construction Worker	ET_{out}	hr/day	10
Outdoor Inhalation Rate (daily):**			
Resident Child	IR_a	m^3/day	2.5
Resident Adult	IR_a	m^3/day	5.0
Non-Residential Worker	IR_a	m^3/day	5.0
Construction Worker	IR_a	m^3/day	16.2
Skin Surface Area for Incidental Dermal Contact with Soil:			
Resident Child	SA_{soil}	cm^2/day	2800
Resident Adult	SA_{soil}	cm^2/day	5700
Non-Residential Worker	SA_{soil}	cm^2/day	3300
Construction Worker	SA_{soil}	cm^2/day	3300
Skin Surface Area for Incidental Dermal Contact with Water:			
Resident Child	SA_{gw}	cm^2/day	2800
Resident Adult	SA_{gw}	cm^2/day	5700
Non-Residential Worker	SA_{gw}	cm^2/day	3300
Construction Worker	SA_{gw}	cm^2/day	3300
Skin Surface Area for Whole-Body Dermal Contact with Water:			
Resident Child	$SA_{gw\text{-}wb}$	cm^2/day	6600
Resident Adult	$SA_{gw\text{-}wb}$	cm^2/day	18000
Soil to Skin Adherence Factor:			
Resident Child	AF	mg/cm^2	0.2
Resident Adult	AF	mg/cm^2	0.07
Non-Residential Worker	AF	mg/cm^2	0.2
Construction Worker	AF	mg/cm^2	0.3
Event Frequency for Incidental Dermal Contact with Soil			
Resident Child	EV_{soil}	event/day	1
Resident Adult	EV_{soil}	event/day	1
Non-Residential Worker	EV_{soil}	event/day	1
Construction Worker	EV_{soil}	event/day	1
Event Frequency for Incidental Dermal Contact with Water			
Resident Child	EV_{gw}	event/day	1
Resident Adult	EV_{gw}	event/day	1
Non-Residential Worker	EV_{gw}	event/day	1
Construction Worker	EV_{gw}	event/day	1
Event Frequency for Whole-Body Dermal Contact with Water			
Resident Child	EV_{gw_wb}	event/day	1
Resident Adult	EV_{gw_wb}	event/day	1

Table E-4
Exposure Factors

Parameter	Symbol	Unit	Default
Event Duration for Incidental Dermal Contact with Water			
Resident Child	t_{event}	hr/event	1
Resident Adult	t_{event}	hr/event	1
Non-Residential Worker	t_{event}	hr/event	1
Construction Worker	t_{event}	hr/event	1
Event Duration for Whole-Body Dermal Contact with Water			
Resident Child	t_{event_wb}	hr/event	0.33
Resident Adult	t_{event_wb}	hr/event	0.25

Notes:

*: Calculated as hourly indoor inhalation rate times exposure time for indoor inhalation

**: Calculated as hourly outdoor inhalation rate times exposure time for outdoor inhalation

Table E-5
Fate and Transport Parameters

Parameter	Symbol	Unit	Soil Type 1	Soil Type 2	Soil Type 3
SOIL PARAMETERS:					
Soil Source Dimension Parallel to Wind Direction	W_a	cm	1500	1500	1500
Depth to Subsurface Soil Sources	d_{ts}	cm	91.44	91.44	91.44
Depth of Surficial Soil Zone	d_s	cm	91.44	91.44	91.44
Depth to Soil Vapor Measurement	dsv	cm	91.44	91.44	91.44
VADOSE ZONE:					
Total Soil Porosity	θ_T	cm^3/cm^3-soil	0.38	0.44	0.44
Volumetric Water Content	θ_{ws}	cm^3/cm^3	0.08	0.17	0.21
Volumetric Air Content	θ_{as}	cm^3/cm^3	**0.30**	**0.27**	**0.23**
Thickness	h_v	cm	**295**	**295**	**295**
Dry Soil Bulk Density	ρ_s	g/cm^3	1.5	1.5	1.5
Fractional Organic Carbon Content	f_{ocv}	g-C/g-soil	0.006	0.006	0.006
SOIL IN CRACKS:					
Total Soil Porosity	θ_{Tcrack}	cm^3/cm^3-soil	0.38	0.44	0.44
Volumetric Water Content	θ_{wcrack}	cm^3/cm^3	0.08	0.17	0.21
Volumetric Air Content	θ_{acrack}	cm^3/cm^3	**0.30**	**0.27**	**0.23**
CAPILLARY FRINGE:					
Total Soil Porosity	θ_{Tcap}	cm^3/cm^3-soil	0.38	0.44	0.44
Volumetric Water Content	θ_{wcap}	cm^3/cm^3	**0.34**	**0.40**	**0.40**
Volumetric Air Content	θ_{acap}	cm^3/cm^3	**0.038**	**0.044**	**0.044**
Thickness	h_c	cm	5	5	5
GROUNDWATER PARAMETERS:					
Depth to Groundwater	L_{gw}	cm	300	300	300
GW Source Dimension Perpendicular to GW Flow Direction	Y	cm	1500	1500	1500
GW Source Dimension Parallel to GW Flow Direction	W_{ga}	cm	1500	1500	1500
Total Porosity in the Saturated Zone*	θ_{TS}	cm^3/cm^3	0.38	0.44	0.44
Dry Soil Bulk Density (Saturated Zone)*	ρ_{ss}	g/cm^3	1.5	1.5	1.5
Fractional Organic Carbon Content in the Saturated Zone*	f_{ocs}	g-C/g-soil	0.006	0.006	0.006

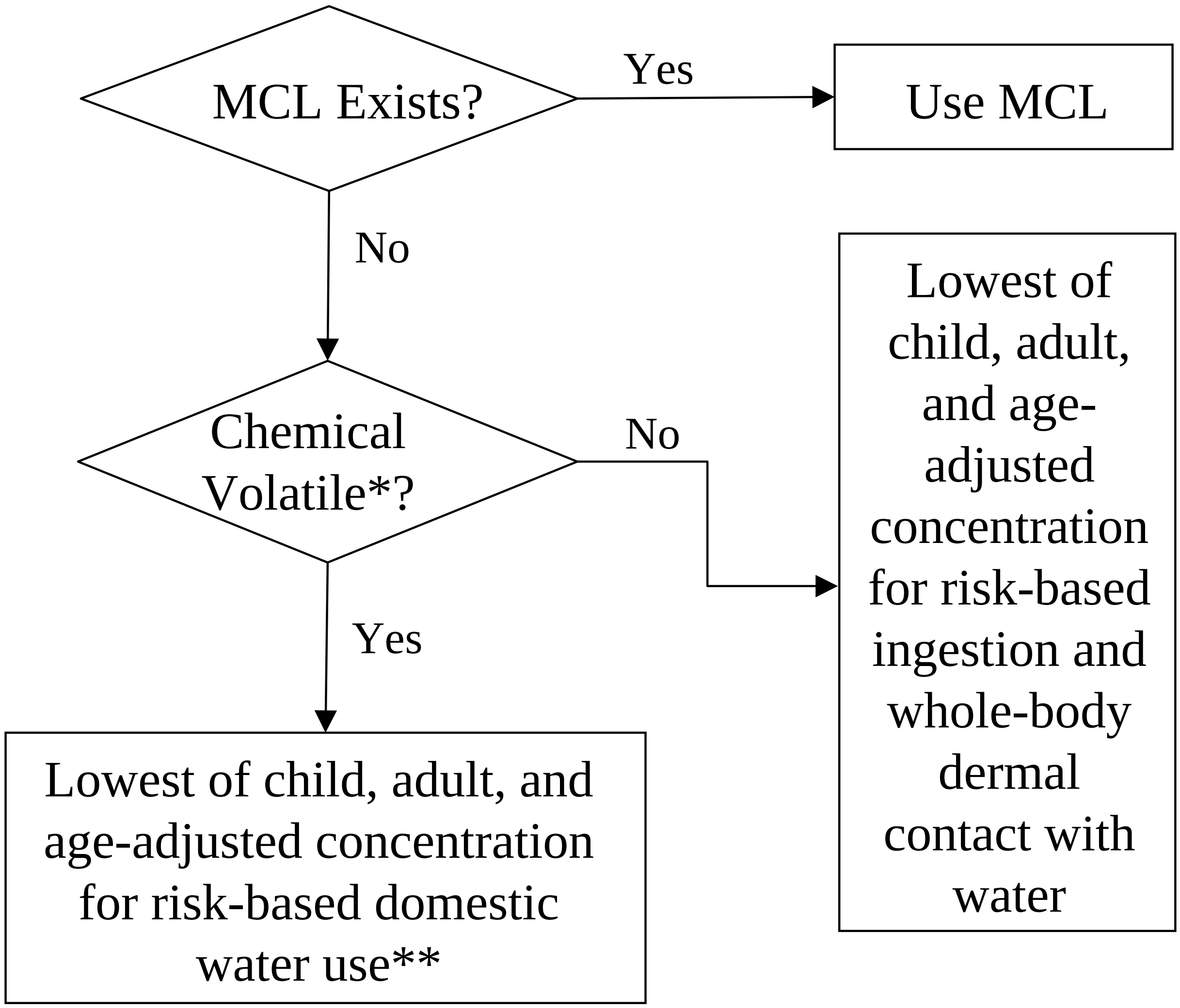
Table E-5
Fate and Transport Parameters

Parameter	Symbol	Unit	Soil Type 1	Soil Type 2	Soil Type 3
Groundwater Mixing Zone Thickness	δ_{gw}	cm	200	200	200
Hydraulic Conductivity in the Saturated Zone	K	cm/year	625000	625000	625000
Hydraulic Gradient in the Saturated Zone	i	cm/cm	0.004	0.004	0.004
Groundwater Darcy Velocity	U_{gw}	cm/year	**2500**	**2500**	**2500**
Infiltration Rate of Water Through Vadose Zone	I	cm/year	14	14	14
AMBIENT AIR PARAMETERS:					
Breathing Zone Height	δ_a	cm	200	200	200
Inverse of Mean Concentration at Center of Square Source	Q/C	$(g/m^2\text{-}s)/(kg/m^3)$	81.64	81.64	81.64
Fraction of Vegetative Cover	V	m^2/m^2	0.5	0.5	0.5
Mean Annual Wind Speed	U_m	m/s	4.69	4.69	4.69
Equivalent Threshold Value of Windspeed	U_t	m/s	11.32	11.32	11.32
Windspeed Distribution Function from Cowherd et. al, 1985	F(x)	unitless	0.194	0.194	0.194
ENCLOSED SPACE PARAMETERS:					
Enclosed Space Air Exchange Rate:					
Residential Structure	ER	1/24 hrs	12.096	12.096	12.096
Non-Residential Structure	ER	1/24hrs	19.872	19.872	19.872
Enclosed Space Volume/Infiltration Area:					
Residential Structure	L_B	cm	200	200	200
Non-Residential Structure	L_B	cm	300	300	300
Volatalization Factor for Domestic Water Use (K)	K	L/m^3	0.5	0.5	0.5
Enclosed Space Foundation or Wall Thickness:					
Residential Structure	L_{crack}	cm	15	15	15
Non-Residential Structure	L_{crack}	cm	15	15	15
Area Fraction of Cracks in Foundation/Walls:					
Residential Structure	η	cm^2/cm^2	0.001	0.001	0.001
Non-Residential Structure	η	cm^2/cm^2	0.001	0.001	0.001

Notes:

The values in **bold** are calculated .

* These parameters not used for DTL or Tier 1 RBTL caculations, but may be required for Tier 2 SSTLs.



MCL: Maximum contaminant level

* Chemical is volatile if MW < 200 and H (dimensionless) > 4.2 x 10^{-4}.

** Domestic water use includes ingestion of water, indoor inhalation of vapors due to water use, and dermal contact.

Figure E-1. Determination of Groundwater Target Concentration at POE

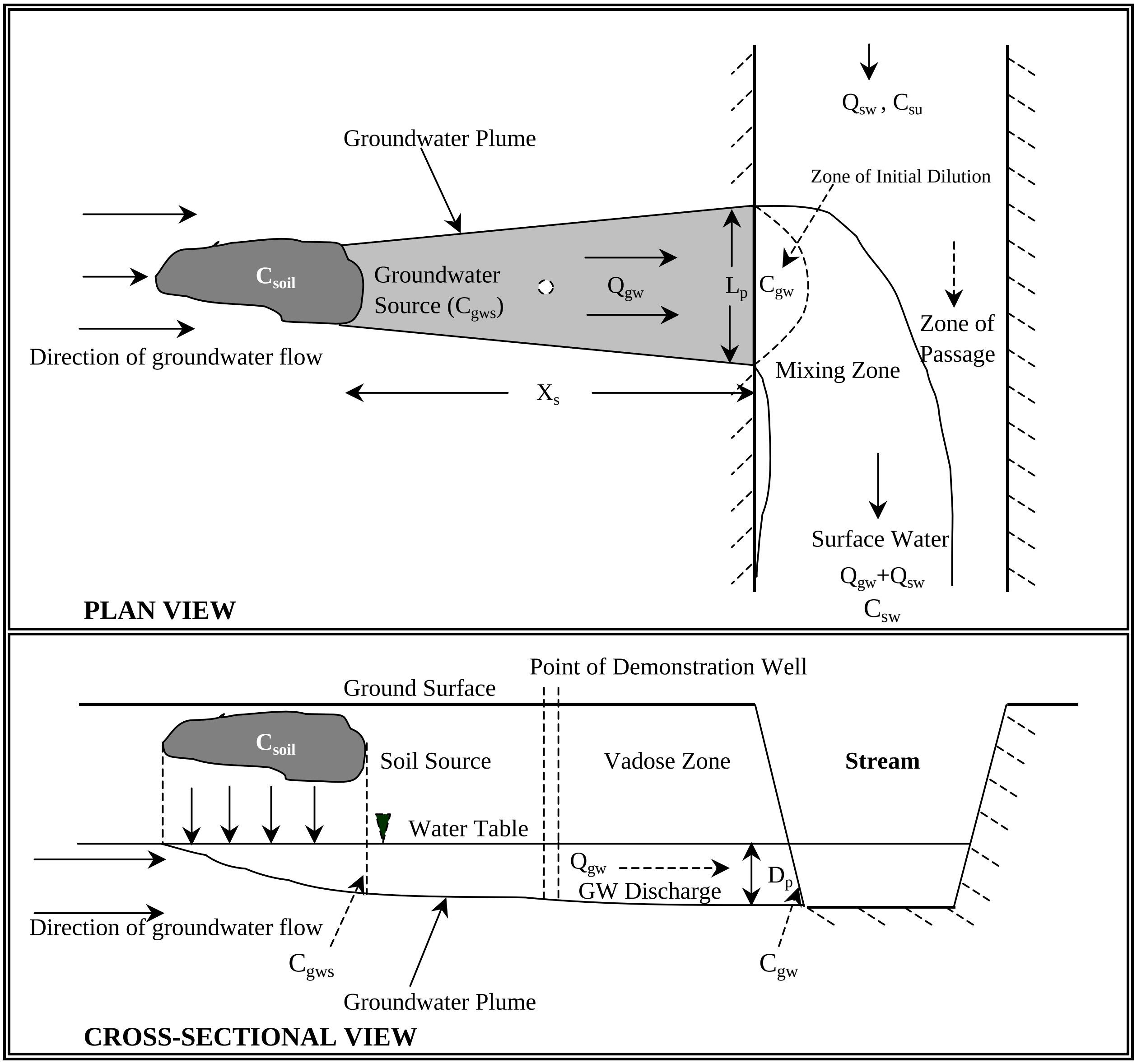


Figure E-3. Schematic of Leachate Migration from the Soil to a Stream

Explanation of Symbols

Q_{sw} = Stream flow upstream of the point of groundwater discharge[ft^3/day]
C_{su} = Concentration upstream of the groundwater discharge [mg/L]
Q_{gw} = Impacted groundwater discharge into the stream [ft^3/day]
C_{sw} = Allowable downstream concentration, i.e., specific water quality criteria to be met beyond mixing zone [mg/I
C_{gw} = Allowable concentration in the groundwater discharge to the stream [mg/L]
C_{gws} = Allowable concentration in the groundwater at the edge of the soil source [mg/L]
C_{soil} = Allowable soil concentration at the source [mg/kg]
L_p = Width of groundwater plume discharging to the stream [ft]
D_p = Thickness of groundwater plume discharging to the stream [ft]
X_s = Distance from the downgradient edge of the groundwater source to the stream [ft]

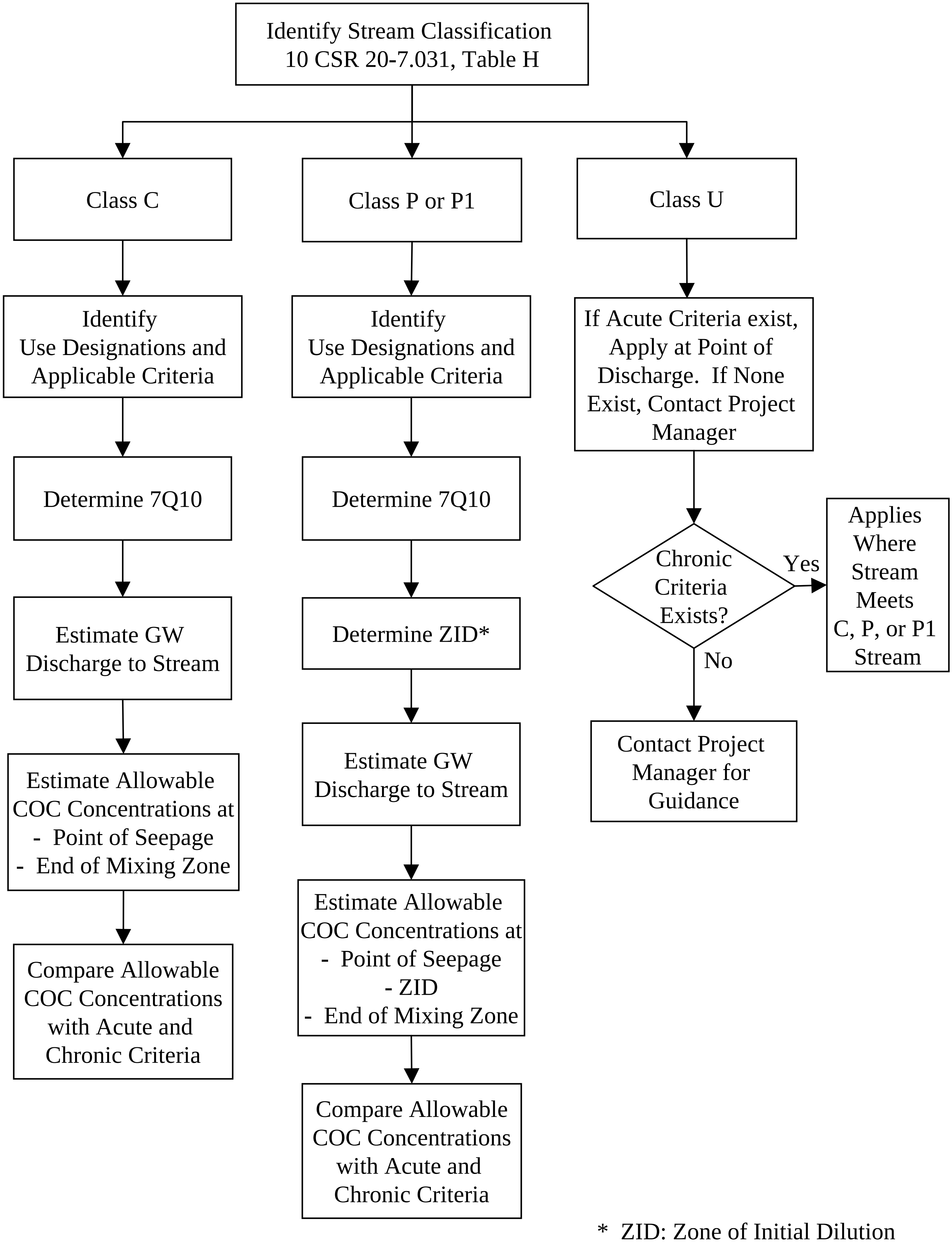


Figure E-4. Procedure for Protection of Stream Body

APPENDIX F
ECOLOGICAL RISK ASSESSMENT CHECKLISTS

Ecological Risk Assessment
Screening Checklist for Potential Receptors and Habitat
Level 1, Checklist A

1. Is the boundary of the contaminated area less than ½ mile to a surface water body (stream, river, pond, lake, etc.)?

2. Are wetlands (as defined by the 1987 Corps of Engineers' Delineation Manual) on or adjacent to the site?

3. Are contaminated soils uncovered or otherwise accessible to ecological receptors and the elements?

4. Are there karstic features (see Ecological Risk Assessment Figure #2 for definition) on or within ½ mile of the boundary of the contaminated area?

   Note: A professional opinion may be necessary to make this determination. The Missouri Environmental Geology Atlas (MEGA), published recently by the Department of Natural Resources, Division of Geology and Land Survey (DGLS) provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format that can assist in this determination. MEGA, including software to view the data sets, may be obtained from DGLS by calling (573) 368-2125.

5. Are there federal or state rare, threatened, or endangered species on or within ½ mile of the contaminated area? Note: The ½ mile criterion does not apply to situations where a hydrological connection exists between the site and karstic features. Contact the Missouri Department of Conservation for state-listed species and the U.S. Fish and Wildlife Service for federally listed species.

6. Are there one or more environmentally sensitive areas (see Ecological Risk Assessment Figure #1 for definition) at or within ½ mile of the contaminated area?

7. Are commercially or recreationally important species (fauna or flora) on or within ½ mile of the contaminated area?

If the answer is "Yes" to any of the above questions, then complete Ecological Risk Assessment Checklist for Potential Exposure Pathways, Checklist B.

Ecological Risk Assessment
Screening Checklist for Potential Receptors and Habitat
Level 1, Checklist B

1.a.) Can contaminants associated with the site leach, dissolve, or otherwise migrate to groundwater?
1.b.) Are contaminants associated with the site mobile in groundwater?
1.c.) Does groundwater from the site discharge to ecological receptor habitat?
Question 1: Could contaminants associated with the site reach ecological receptors via groundwater?

2.a.) Is Non-Aqueous Phase Liquid (NAPL) present at the site?
2.b.) Is NAPL migrating?
2.c.) Could NAPL discharge occur where ecological receptors are found?
Question 2: Could contaminants from the site reach ecological receptors via migration of NAPL?

3.a.) Are contaminants present in surface soils?
3.b.) Can contaminants be leached from or be transported by erosion of surface soils?
Question 3: Could contaminants reach ecological receptors via erosional transport of contaminated soils or via precipitation runoff?

4.a.) Are contaminants present in surface soil or on the surface of the ground?
4.b.) Are potential ecological receptors on the site?
Question 4: Could contaminants reach ecological receptors via direct contact?

5.a.) Are contaminants present on the site volatile?
5.b.) Could contaminants on the site be transported in air as dust or particulate matter?
Question 5: Could contaminants reach ecological receptors via inhalation of volatilized contaminants or contaminants adhered to dust in ambient air or in subsurface burrows?

6.a.) Are contaminants present in surface and shallow subsurface soils or on the surface of the ground?
6.b.) Are contaminants found in soil on the site taken up by plants growing on the site?
6.c.) Do potential ecological receptors on or near the site feed on plants (e.g., grasses, shrubs, forbs, trees, etc.) found on the site?
6.d.) Do contaminants found on the site bioaccumulate?
Question 6: Could contaminants reach ecological receptors via direct ingestion of soil, plants, animals or contaminants?

7.a.) Are there karstic features (see Ecological Risk Assessment Figure #2 for definition) on or within ½ mile of the contaminated area?
7.b.) Is there a hydrogeological connection between the site and karstic features such as seeps, springs, streams or other surface water bodies?
Question 7: Could contaminants reach ecological receptors via transport through a karst system?

Note: A professional opinion may be necessary to answer 7.a, 7.b, and Question 7. The Missouri Environmental Geology Atlas (MEGA), published recently by the Missouri Department of Natural Resources, Division of Geology and Land Survey (DGLS), provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format, that can assist in answering these questions. MEGA, including software to view the data sets, can be obtained from DGLS by calling (573) 368-2125. The determination of proximity to karst features/topography under questions 7b and 7 of Checklist B does not always require a field determination. However, in some cases, a field determination may be appropriate.

If the answer to one or more of the seven above questions is “Yes”, the department may require further assessment to determine whether the site poses an unacceptable risk to ecological receptors.

Ecological Risk Assessment
Figure #1: Environmentally Sensitive Areas

An Environmentally Sensitive Area is of special significance due to its flora or fauna, the sensitive nature of its natural features, historical considerations, or other reasons associated with the environment.

Examples of environmentally sensitive areas include, but are not limited to, the following:

- National and state parks,
- Designated and proposed federal and state wilderness and natural areas,
- Endangered, rare, and threatened species habitat as designated by the U.S. Department of the Interior or the Missouri Department of Conservation,
- National monuments,
- National and state historic sites,
- National and state lakeshore and river recreational areas,
- Federal or state designated scenic or wild rivers,
- Habitat of federal or state designated or proposed endangered, rare, or threatened species, and species under review as to their endangered, rare, or threatened status,
- National and state preserves and forests,
- National and state wildlife refuges,
- Critical fish and shellfish spawning areas,
- Critical migratory pathways and feeding areas for anadromous fish species within river reaches or areas in lakes where such species spend extended periods of time,
- Terrestrial areas used for breeding by large or dense aggregations of faunal species,
- State lands designated by the Missouri Department of Conservation for wildlife or game management,
- Wetlands as defined by the 1987 Corps of Engineers Delineation Manual and
- Outstanding state resource waters as designated by the Missouri Clean Water Commission.

Ecological Risk Assessment
Figure #2: Karst Features

Karst: A distinctive set of geomorphic landforms resulting from the development of extensive subsurface solution channels and caves in carbonate rocks (Boulding, 1995).

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APPENDIX G
A METHOD FOR DETERMINING IF A WATER BEARING UNIT SHOULD BE CONSIDERED AN AQUIFER

Division of Geology and Land Survey
Department of Natural Resources
January 2004

A METHOD FOR DETERMINING IF A WATER BEARING UNIT SHOULD BE CONSIDERED AN AQUIFER

Several criteria must be met for a water-bearing zone to be considered a potentially usable aquifer. First, the water quality must be such that consuming the water does not pose an immediate or long-term risk to human health. Second, the water-bearing materials must yield at least enough water to serve a useful purpose. Realistically, if the water-bearing materials cannot adequately supply a single household, then it is doubtful if they would be considered an aquifer. Two factors controlling the volume of groundwater that can be produced from water-bearing materials are the hydraulic conductivity and the saturated thickness of the potential aquifer. It is necessary for both of these factors to be considered. The greater the hydraulic conductivity of the water-bearing materials, the greater the yield potential. However, a thick sequence of low hydraulic conductivity materials may actually yield more water than a thinner unit having a much higher hydraulic conductivity.

The technique described below was developed to aid in determining if a water-bearing unit should be considered an aquifer. A series of calculations were made based on several assumptions. It was assumed that to be considered a viable water supply, a well would need to be able to produce a minimum of 0.25 gallons of water per minute (360 gallons per day) for a period of 10 days. The calculated drawdown at the well at the end of this period could not exceed one-third of the saturated thickness of the water-bearing unit. A storage coefficient of 0.001 was assumed. The well was assumed to have an efficiency of 100 percent. The Theis nonequilibrium well equation (a.k.a., nonleaky artesian formula) was used to calculate the aquifer transmissivity necessary to meet these parameters for aquifer thickness between 10 to 200 feet. Hydraulic conductivity values were determined by dividing the calculated transmissivity values by the full saturated thickness.

The calculated hydraulic conductivity values were plotted against the saturated thickness of the aquifer (see graph on page G-4). The data plotted as a power function. A curve-fitting program was applied to derive the following empirical equation:

$$K = b^{-2.04} \times 1447 \qquad (1)$$

where,

K = hydraulic conductivity (gpd/ft^2), and
b = aquifer saturated thickness (feet).

If the saturated thickness of the water-bearing zone under consideration is known, then the equation can be used to calculate the average hydraulic conductivity that will be necessary to meet the minimum aquifer requirements listed above. Conversely, if a representative value for the hydraulic conductivity has been determined, then the equation can be re-written to determine the minimum saturated thickness that will be needed to meet the minimum aquifer requirements shown above. That equation is:

$$b = K^{-0.496} \times 35.33 \qquad (2)$$

Hydraulic conductivity values in units of gpd/ft^2 and ft/day are commonly used in the water supply field but are not widely used in environmental work where hydraulic conductivity values are typically reported in units of cm/sec. To convert a hydraulic conductivity value measured in gpd/ft^2 to cm/sec, multiply it by 7.75×10^{-5}.

Below are two examples:

EXAMPLE 1

Test drilling and slug tests show that a water-saturated sandy silt has a hydraulic conductivity of 2.5×10^{-4} cm/sec. A thick clay unit underlies the materials, and the saturated thickness of the sandy silt unit is 23 feet. Does it meet the criteria necessary to be considered a potentially usable aquifer?

We will assume the water quality meets minimum requirements for potability. A hydraulic conductivity of 2.5×10^{-4} cm/sec is equal to 3.2 gpd/ft. With this hydraulic conductivity, the minimum saturated thickness needed is from Equation (2):

$$3.2^{-0.496} \times 35.33 \text{ or } 19.8 \text{ feet}$$

Based on the above, the zone would be considered a potentially usable aquifer.

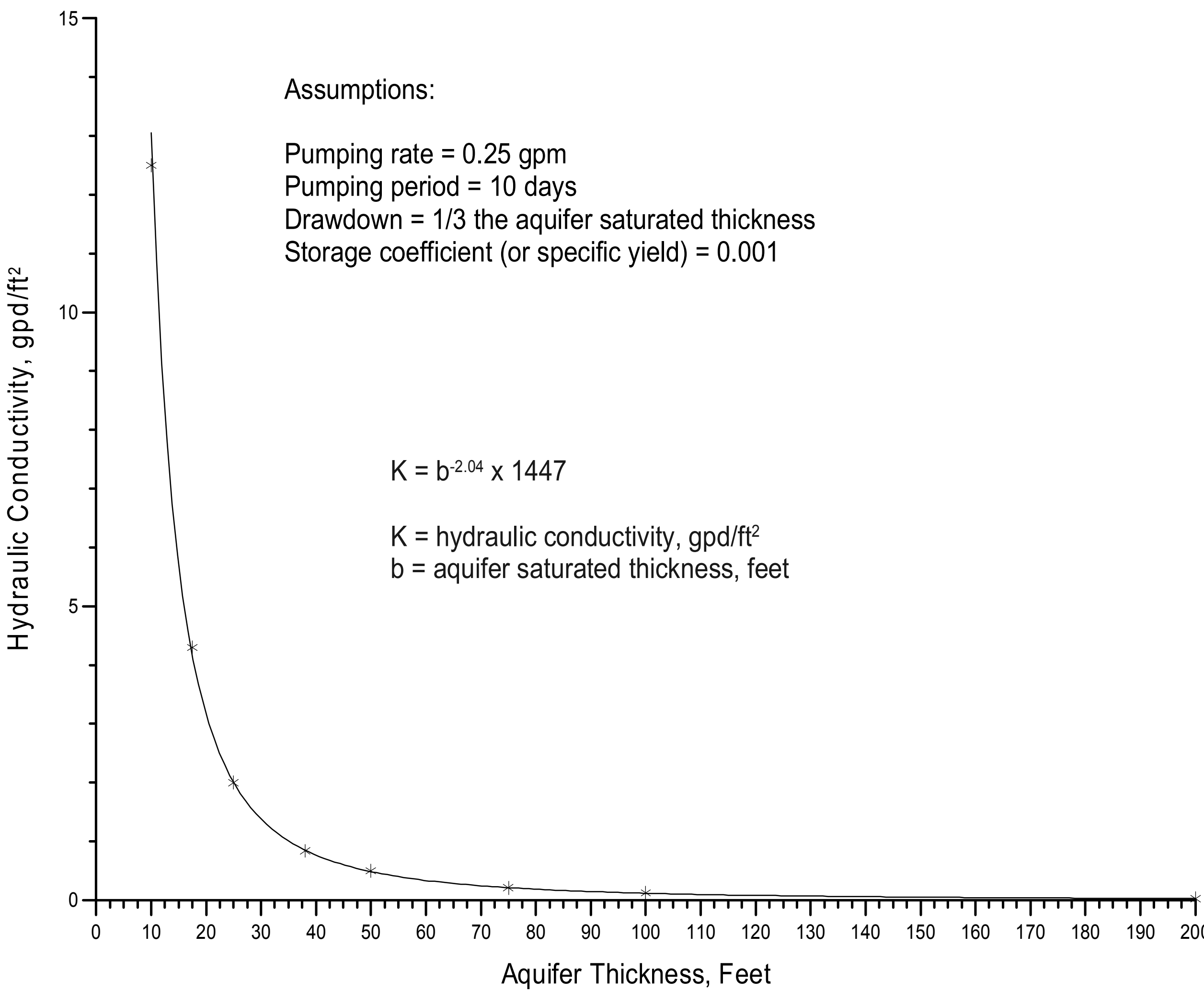
EXAMPLE 2

Test drilling below a site shows 80 feet of fairly uniform sandy clay till. What would be the minimum average hydraulic conductivity necessary for this material to comprise an aquifer?

$K = 80^{-2.04} \times 1447$
$K = 0.19$ gpd/ft^2 or 1.47×10^{-5} cm/sec

Based on this technique, 80 feet of sandy clay till having an average hydraulic conductivity of 1.47×10^{-5} cm/sec (or 0.19 gpd/ft^2) would be considered a usable aquifer.

Changing any of the aquifer parameters and yield assumptions listed above would, of course, change equations 1 and 2 above. Some argument could be made as to the assumed pumping period of 10 days. Perhaps a pumping period of 1 day might seem more appropriate. However, it must be remembered that the Theis nonequilibrium equation assumes confined (artesian) conditions. For it to be entirely valid, the saturated thickness of the aquifer must remain essentially unchanged. The drawdown must not lower the potentiometric surface an appreciable distance below the top of the aquifer. Most shallow aquifers that will be considered under this rule will likely be unconfined. As drawdown occurs in an unconfined aquifer, the saturated thickness of the aquifer within the drawdown cone decreases. Thus, the transmissivity (which is the product of the hydraulic conductivity and the saturated thickness) also decreases. Reducing the saturated thickness of an unconfined aquifer by one-third will reduce its transmissivity proportionally. Because of this, the assumed drawdown of one-third the aquifer thickness is probably optimistic for an unconfined aquifer. The actual drawdown will be somewhat larger if the well is actually pumped 0.25 gpm for 10 days. If a shorter pumping period is selected for consideration, then the allowable drawdown should be changed from one-third the saturated thickness of the aquifer to a more conservative value, such as 10 percent of the saturated thickness of the aquifer.



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Soil Gas Sampling Protocol

Departmental Missouri Risk-Based Corrective Action Technical Guidance

H. 1 Introduction and Scope

The Departmental *Missouri Risk-Based Corrective Action (MRBCA) Technical Guidance* ("Guidance") requires evaluation of the indoor air inhalation pathway at sites having contamination in soil, groundwater, or both. For sites where the indoor air inhalation pathway is complete currently or in the future and soil or groundwater representative concentrations exceed Tier 2 Site-Specific Target Levels ("SSTLs") for the indoor air inhalation pathway, the guidance allows the pathway to be further evaluated through soil gas sampling. Such sampling must be conducted under a work plan approved by the Missouri Department of Natural Resources (MDNR).

The purpose of this document is to provide guidance for conducting soil gas sampling at contaminated sites. (Note that this guidance is, in substance, identical to that used in the *Missouri Risk-Based Corrective Action Process for Petroleum Storage Tanks.)* The routine evaluation of the indoor inhalation pathway at contaminated sites is a relatively recent development. As a result, methods, procedures, and technology related to evaluating the pathway continue to evolve. While this guidance is, in part, prescriptive, MDNR does not intend for this guidance to be overly limiting with respect to the use of other appropriate methods, procedures, and equipment for measuring concentrations of chemicals of concern in soil gas. Even so, departures from this guidance must be presented in a work plan submitted to MDNR and utilized only with MDNR approval.

A work plan is required for all soil gas sampling at MRBCA sites. The work plan must be submitted to and approved by MDNR prior to the occurrence of the soil gas sampling event.

This protocol does not specifically pertain to sub-slab vapor sampling (a means of collecting soil gas samples from beneath a building via the installation of monitoring points through the foundation of the building). If site conditions warrant collection of sub-slab vapor samples, MDNR recommends that procedures under development by the United States Environmental Protection Agency ("USEPA") be used. USEPA's current sub-slab sampling guidance is entitled *Draft Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations.* When final guidance becomes available, it shall be used in lieu of, or in addition to, the referenced SOP.

Sub-slab sampling, whether in accordance with USEPA or other guidance or procedures, must be conducted under a MDNR-approved work plan.

This protocol is not intended to prohibit those conducting evaluations under the MRBCA process from using means other than those specified herein to measure soil gas concentrations at a contaminated site. However, departures from this guidance must be specifically detailed in a written work plan submitted to MDNR and may be implemented at a contaminated site only with the written approval of MDNR. For consistency, MDNR prefers that soil gas sampling be conducted in accordance with this protocol unless extenuating circumstances make application of this protocol impractical.

This protocol is designed to facilitate a quantitative evaluation of soil gas. Passive soil gas monitoring is generally a qualitative activity used to guide the installation of permanent sampling points. As such, passive soil gas monitoring may not be used to quantitatively monitor soil gas or assess risks associated with vapor intrusion. Passive soil gas monitoring may be used preliminarily to assist in planning a quantitative soil gas sampling event.

H.2. Soil Gas Probe Installation

H.2.1 Installation Requirements.

A. The Missouri Well Construction Rules at 10 CSR 23-1.010 through 10 CSR 23-6.060 govern the installation and abandonment of monitoring wells, the definition of which includes wells used for soil gas monitoring. Refer to these rules prior to installing soil gas sampling points in the field.

B. Installation of monitoring wells greater than 10 feet in depth and having a riser less than 2 inches in diameter or installed in a borehole less than 6 inches in diameter require a variance issued by MDNR's Geological Survey and Resources Assessment Division (GSRAD).

H.2.2 Sampling Depth.

A. To the extent possible, soil gas sample depths should be chosen to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface, and to ensure that consistent and representative samples are collected. In determining appropriate sampling depths, strong consideration should be given to the lithology of the subsurface. Under no circumstances may soil gas samples be collected from a depth of less than 18 inches.

B. Soil gas sampling depths must be consistent from sampling point to sampling point.

C. Generally, soil gas samples must be collected at a minimum of two discrete depths at each sampling point. Where contamination in soil is very shallow or groundwater is very shallow (i.e., less than approximately 5 feet below the ground surface), one sample from a single depth might be sufficient.

D. One of the two soil gas samples collected at each sampling point must be collected at a depth no greater than 3 feet below the foundation of the enclosed space or potential future enclosed space. The depth at which the second sample is collected will be dependent on site conditions, primarily the depth to contamination.

E. For structures having basements, one or more soil gas samples must be collected adjacent to basement walls (i.e., no further than 5 feet from the wall and, generally, at a depth approximately equal to the midpoint of the wall; this depth might need to vary depending on the characteristics of the structure). Unless soil or groundwater contamination is found below the building, soil gas sampling adjacent to the basement walls need only occur on the side or sides of the building where the contamination is found (e.g., if the soil or groundwater contamination is south of the building, soil gas sampling must, at a minimum, occur on the south side of the building). If soil or groundwater contamination is found below the elevation of the basement floor, soil gas samples must also be collected just below the elevation of the floor.

F. For structures without basements, soil gas samples should be collected below the depth of the foundation, with the first sample collected at a depth of no more than 3 feet.

G. For hypothetical future buildings, if there is no other information available to select depth, soil gas samples should be taken at target depths of approximately 3 feet and 10 feet below ground surface. This method assures that data is available to assess vapor intrusion threats to both "slab-on-grade" buildings and those having basements. If groundwater is too shallow to allow sampling at one or both of these depths, samples should be collected immediately above the capillary fringe or the top of soil contamination. If soil contamination extends to the surface, sample at a depth approximately equal to the anticipated depth of the future structure's foundation.

H. In all cases, if groundwater is too shallow to allow soil gas sampling at the depths specified above, samples shall be collected immediately above the capillary fringe. If soil contamination extends to the surface, sample at a depth just below the expected or actual foundation or floor of the structure.

H.2.3 Lateral Spacing of Soil Gas Sampling Points

A. Soil gas sampling is intended to assess vapor intrusion threats from soil and groundwater to existing or hypothetical future buildings. Therefore, sampling points should be laterally spaced to adequately represent soil gas concentrations proximate to such structures, taking into consideration the location of contamination relative to the structures. The actual number of soil gas sampling points necessary for a given site will depend on the size and number of buildings, the location of the buildings relative to soil and groundwater contamination, and, for the evaluation of hypothetical future structures, the extent or size of the contamination plume. The following provisions should be considered as general guidelines rather than specific requirements. The locations and spacing of soil gas sampling points will ultimately be dependent on site-specific characteristics.

B. Generally, soil gas sampling points should be located along each side of each existing building that is proximate to soil or groundwater contamination. In addition, for existing buildings, samples should be collected above the area of highest contamination. However, if contamination is located to one side of an existing structure, the collection of samples only from that side of the structure might be adequate. If any wall of the structure exceeds 50 feet in length, a minimum of two sampling points is required along that wall.

C. To assess vapor intrusion threats to future structures, sampling points must be installed in the area having the highest contaminant concentrations on the site. Generally, four sampling points should be utilized to evaluate future structures. However, if the size of the plume exceeds 2,500 square feet, more than four sampling points will be required, with the total number dependent on the overall size of the plume. In general, sampling points should be spaced no greater than 50 feet apart and preferentially placed within the anticipated footprint of the future structure, if known.

H.2.4. Probe Construction Materials.

A. Sample probes consist of a probe tip through which the soil gas sample is collected, and probe tubing that extends from the probe tip to the ground surface.

B. Sample probe tubing should be of a small diameter (1/8 to 1/4 inch). Diameter selection should consider site soil types. In general, smaller tubing diameters can result in higher sample vacuum conditions, which can make sample collection more difficult.

C. The sample probe should be constructed of materials that will not react or interact with target compounds. Suggested materials are nylon, polyethylene, copper, poly vinyl chloride (PVC), or stainless steel. If copper is used, the copper must first be adequately cleaned to remove oil residue that might be present from the manufacturing process. Generally, nylon tubing should be used

D. The probe tip should be covered with fine screen or connected to a short (< 2 feet) section of perforated pipe, glass frit, tubing, or screen mesh.

H.2.5. Probe Installation.

A. MDNR recommends that permanent probes, wells, or other soil gas sampling devices be installed to allow for the assessment of seasonal variability (MDNR requires that a minimum of two soil gas sampling events occur at any site at which soil gas sampling is conducted, as discussed at H.3 below). However, temporary sampling points, such as through the probe rods of a direct push drill machine, may be used with the permission of MDNR.

B. Boreholes may be installed using direct push or hollow-stem auger drilling equipment or hand-driven using a rotary hammer or a hand auger. Note, however, that direct push probes might not be suitable for all soil conditions, as smearing of the sidewalls can occur in fine-grained soils. Such smearing could preclude passage of gases from the soil into the borehole.

C. Before any drilling activities, utility clearance for the installation area should be obtained. In addition, utilities proximate to the contamination must be identified and assessed as possible soil gas conduits. Utilities near or above contamination must be screened using a PID or FID (as appropriate) and the results recorded.

D. The borehole is advanced to the target sampling depth. If samples will be collected at multiple depths within the same borehole, the borehole is initially advanced to the deepest sampling point and the deepest sampling point installed first.

E. The probe tip is placed midway between the top and bottom of the sampling interval within a sand pack extending 6 inches above and below the sampling interval. The grain size of the sand pack should be appropriately sized (for example, no smaller than the adjacent formation) and installed to minimize disruption of airflow to the sampling tip.

F. At least 1 foot of dry granular bentonite should be placed on top of the sand pack to preclude the infiltration of hydrated bentonite grout into the sand pack. Refer to Figure 1 for an illustration of this sealing method.

G. The borehole should be grouted to the surface (or, for nested samplers, the bottom of the next sampling interval) with hydrated bentonite. Adequately sealing soil gas sampling probes is very important to minimize the exchange of atmospheric air with the soil gas and to maximize the representativeness of the sample. The surface seal should be a minimum of 2.5 feet thick. If conditions warrant shallow sampling depths, great care should be taken in installing the surface seal to limit atmospheric infiltration.

H. If multiple sampling points are installed within a single borehole, the borehole must be grouted between sampling points. One foot of dry granular bentonite must be placed between the filter pack and the grout at each sampling location within the borehole, as illustrated by Figure 1.

I. Tubing must be properly marked at the surface to identify the probe location and depth. Particularly when multiple probes are installed within a single borehole, tubing must be labeled immediately upon installing each separate probe.

J. To minimize any separation between the soils and the outside of the probe, avoid lateral movement of probes once they have been installed.

K. Examples of a single depth soil gas probe and a multi-depth or "nested" soil gas probe are shown in Figure 1. Figure 1 is only an example: soil gas sampling points need not necessarily be constructed in strict accordance with the figure.

L. Documentation of subsurface soil stratigraphy via borehole logging and other methods can be very important in evaluating soil gas data. While delineation of contamination should be largely complete at any site undergoing soil gas sampling, MDNR recommends that soils be logged, field screened, and sampled for COC analysis during probe installation for the purpose of providing further information regarding the distribution of contamination. Soil stratigraphy data can be very important in determining soil gas fate and transport.

H.2.6. Surface Completion.

A. Unless soil gas probes are properly abandoned the same day they are installed, probes must be properly secured, capped, and completed to prevent infiltration of water or ambient air into the subsurface and to prevent accidental damage or vandalism. For surface completions, the following components may be installed, as necessary:

   i. Gas-tight valve or fitting for capping the vapor point;

   ii. Fitting for connection to above ground sampling equipment;

   iii. Protective flush mounted or above ground well vaults, and/or

   iv. Guard posts.

H.2.7. Probe Abandonment

A. All monitoring wells, including those used for soil gas monitoring, must be abandoned in accordance with Missouri Well Construction Rule 10 CSR 23-4.080, "Plugging of Monitoring Wells." This rule states, in part, that monitoring wells less than 10 feet in depth must be plugged with grout or by returning uncontaminated native material into the hole it was taken from.

B. 10 CSR 23-4.080 also states, in part, that temporary monitoring wells (i.e., closed within 30 days) greater than 10 feet in depth must be plugged by removing any temporary pipe and filling the well from total depth to 10 feet from the surface with approved grout, with the remainder of the well filled with uncontaminated native material or grout. The plugging of all monitoring wells greater than 10 feet in depth must be reported to MDNR on a registration report form supplied by GSRAD.

C. A monitoring well that is abandoned in accordance with 10 CSR 23-1.010 must be plugged immediately.

H.3 Sampling Frequency

H.3.1 Factors affecting soil-gas values.

A. Certain atmospheric and seasonal factors that are not within the evaluator's control can affect soil gas values. For instance, temperature, barometric pressure, and precipitation can affect soil gas values as these factors fluctuate over time. Because these factors will fluctuate, actions must be taken to ensure soil gas data collected at a site is representative of a variety of atmospheric conditions. MDNR has determined that the best way to account for these factors is to require multiple soil gas sampling events over time.

H.3.2. Sampling frequency.

A. At a minimum, two soil gas sampling events must occur at any given site, with no less than three months between events. In cases where measured soil gas values vary significantly from the first to the second event, MDNR may require that additional sampling be conducted. In most cases, the maximum number of sampling events will be four, with the events spaced evenly over a period of one year. Samples must be collected from the same location and depth during each sampling event.

H.3.3 Duplication of sampling events.

A. Under this guidance, soil gas samples may be collected from either permanent or temporary sampling points. Clearly, sampling may be easily duplicated if permanent sampling points are installed. However, if temporary points are used (i.e., those closed within at most 30 days), actions must be taken to ensure that subsequent samples are collected from the same location and depth as the initial samples. To do so, MDNR requires that the location and depth of temporary sampling points be accurately and durably recorded. Sampling points should be marked in the field to ensure that they can be subsequently found. MDNR recommends that the location of each sampling point be recorded using Global Positioning System (GPS) coordinates. GPS coordinates should be accurate to ± 5 feet. The methods used to record the temporary sampling locations and depths and a copy of the actual written record of such information must be included in the soil gas sampling report submitted to MDNR.

H.4. Soil Gas Probe Equilibration and Purging

H.4.1. Monitoring Point Equilibration.

A. During probe installation, subsurface conditions are unavoidably disturbed. The subsurface soil gas profile should be allowed to equilibrate following this disturbance. The following equilibration times are recommended:

- For probes installed using the direct push method, soil gas sampling should not be conducted for at least 30 minutes following probe installation. MDNR recommends waiting several hours.
- For probes installed with hollow stem auger drilling methods, soil gas sampling should not be conducted for at least 48 hours following probe installation.

B. Prior to sampling, soil gas sampling probes should be purged to ensure that stagnant or ambient air is removed from the sampling system and to assure samples collected are representative of subsurface conditions. The following purge procedure is recommended:

- Calculate the volume of the sampling system by summing the volume of the probe screened interval (including filter pack void space, accounting for porosity of sand pack), the volume of tubing from the probe tip to the ground surface, and the volume of above ground tubing connecting the soil probe to the sample collection device.
- Purge the monitoring point until at least three volumes of the full sampling system have been evacuated. Purging should be conducted at flow rates and vacuum conditions similar to those for sample collection (described below).
- If the soil matrix is such that purging as recommended above is not possible due to low or no flow conditions (i.e., gas will not flow or flow is severely restricted), the probe should be advanced deeper to look for zones of higher permeability. If the deeper probe does not encounter a higher permeability zone and low or no flow conditions persist, the probe should be abandoned and a new probe advanced elsewhere on the site.
- If low or no flow conditions are found across the site and soil gas sampling is therefore not possible, the evaluator may propose an alternative method of soil gas sampling, such as sub-slab sampling. Because sub-slab gas samples are generally extracted from the porous granular material underlying a slab, sub-slab sampling may be a practical method of soil gas sampling when subsurface sampling is not. As discussed at H. 1 above, if site conditions warrant sub-slab sampling, the sampling should be conducted in accordance with current EPA sub-slab sampling guidance.

H.5. Soil Gas Sample Collection Procedures

H.5.1 Sample Containers.

A. Samples may be collected in Tedlar bags or gas-tight syringes if samples are analyzed on-site in a mobile laboratory. Syringes may not be used if samples are analyzed off-site at a fixed laboratory. For samples to be analyzed off-site at a fixed laboratory, Summa canisters or Tedlar bags may be used. MDNR recommends working with the laboratory that will analyze the samples in choosing appropriate sample containers. MDNR prefers that small volume – 1 L or 500 mL – Summa canisters be used. Certain situations might warrant the use of a larger Summa canister but, in general, the small volume canisters should be used.

B. The analytical laboratory or other supplier of sample containers must certify that all sample containers supplied by them are free of contaminants at concentrations exceeding contaminant detection levels.

H.5.2. Sampling Flow Rate.

A. An initial sampling rate of 200 milliliters per minute (mL/min) or less is recommended.

B. A regulated flow meter should be placed between the probe and the sample container to control and measure the flow rate.

C. The sampling rate may be modified based on specific field conditions, including the vacuum observed. Data for samples collected at a flow rate exceeding the recommended rate of 200 mL/min shall be flagged in the report submitted to MDNR. MDNR will not necessarily reject flagged data. Flagging is intended to facilitate a more thorough review of the data.

H.5.3. Vacuum Conditions.

A. To measure sample collection vacuum, a vacuum gauge must be placed between the probe and the sample container. MDNR recommends a sampling vacuum of less than 100 inches of water.

B. To achieve the target sampling vacuum, the sampling flow rate should be adjusted using the flow regulator.

C. If the sampling vacuum exceeds 100 inches of water, and a reduction in the sampling flow rate does not reduce the vacuum, continue to attempt to collect the sample, recording flow rate and vacuum conditions. Data for samples collected under a vacuum of greater than 100 inches of water must be flagged. MDNR will not necessarily reject or consider such data suspect. Flagging will simply facilitate a more thorough review of the data.

D. If the sample container cannot be filled within an expected time frame, such time being dependent on the size and type of the sample container and sampling equipment (e.g., tube diameter), discontinue sampling and document vacuum observations. Generally, data from samples collected under such conditions will not be valid.

H.5.4. Field Conditions.

A. Generally, soil gas sampling should not be conducted within 48 hours of a significant precipitation event (for example, 0.5 inch or greater of rain) or comparable on-site watering. However, whether sampling is conducted is dependent on the depth to which soil is wetted relative to the planned depth of sample collection. The depth to which the soil is wetted is dependent, at least in part, on the ground cover, the type of soil, and the soil moisture content prior to the precipitation event. Sampling should not occur if soils are wetted at a depth equal to or greater than the planned sampling depth.

H.5.5. Sample Collection.

A. Aboveground sampling equipment consists of connector tubing, regulated flow meter, pressure gauge, and purging equipment. An example sampling train is shown in Figure 2.

B. Connect aboveground sampling equipment to probe at the surface. Check all sampling system connections and fittings for tightness and obvious deterioration.

C. Quick connect fittings and nylon tubing should be used to ensure vacuum tightness of the system and that chemicals in the air stream are not reacting with or adsorbing to the tubing. Compression fittings should be avoided for all connections except at the Summa canister (if used).

D. Purge at least three volumes of air from the sampling system as described at H.4.1.B above. After purging is complete, close the valve to the purge line and/or disconnect purge apparatus, as appropriate.

E. Connect the sample container to the sampling line, using quick-connect, airtight fittings.

F. Follow the leak test procedures described in Section H.6, below.

G. Open valve and collect sample into sample container, following the sample flow rate and vacuum guidelines discussed above. During sampling, measure and record sample flow rate and vacuum every two to five minutes.

H. Disconnect sample container and immediately label the container with sample identification information.

I. If Summa canisters are used, measure the final pressure of the canister using a pressure gauge. Record the final canister pressure.

J. Store sample containers out of direct sunlight, and do not chill.

H.5.6. Quality Control Samples.

A. The collection of at least one field duplicate per sampling event or one per twenty samples, whichever is greater, is required.

B. Duplicate samples shall be collected in separate sample containers, using the same procedures and at the same location and depth as the original sample.

C. Preferably, duplicate samples should be collected simultaneous to collection of the primary sample using a sampling tee. Alternatively, the duplicate may be collected immediately after the collection of the primary sample.

D. At least one equipment blank must be collected per sampling event or per 25 samples, whichever is greater.

H.5.7. Recordkeeping.

The following information should be recorded in a field notebook or on sampling forms (Figure 3 shows an example field form) and reported to MDNR as necessary to facilitate MDNR's understanding of the procedures utilized at a specific site to collect soil gas data.

A. MDNR recommends that the evaluator construct a relatively simple conceptual site model related to the indoor inhalation pathway. Such a model can be very useful before, during, and after a soil gas sampling investigation. The conceptual site model should, at a minimum, include information on the location of utility corridors and other potential preferential pathways for soil gas migration, depth to groundwater, distances between sources and receptors (include both current and potential future structures), and soil type and soil stratigraphy.

B. Sample identification information, including the locations and depths at which the samples were collected, sample identifiers, date, and time.

C. Field personnel involved in sample collection.

D. Weather conditions (e.g., temperature, wind speed, barometric pressure, precipitation, etc.).

E. Sampling methods, devices, and equipment used.

F. Purge volumes prior to sample collection. Relate the purge volumes to the volume of the sampling equipment, including the tubing connecting the sampling interval to the surface.

G. Volume of soil gas extracted (i.e., volume of each sample).

H. Vacuum of canisters before and after samples collected.

I. If observable, the apparent moisture content of the sampling zone (e.g., dry, moist, saturated). An alternative to a qualitative measurement of soil moisture is to collect a soil sample from the soil gas sampling interval for laboratory measurement of soil moisture. If a soil sample is collected for this purpose, include a copy of the laboratory data sheet.

J. Shipment information, including chain of custody protocols and records.

H.6. Leak Testing

H.6.1. Requirements.

A. Leakage during soil gas sampling may dilute samples with ambient air and produce results that underestimate actual site concentrations or contaminate the sample with external contaminants. Therefore, MDNR is requiring that a leak test be conducted each time a soil gas sample is collected to determine whether leakage has occurred.

B. For each sample, use a hand pump to vacuum test the sampling equipment after assembly.

C. A leak check, or tracer, compound such as isopropanol is recommended to determine if leaks are present. Other compounds such as pentane, isobutane, propane, and butane, may be used as leak check compounds. MDNR may approve the use of other leak check compounds on a request-specific basis.

D. Select a leak check compound that is not known or suspected to be site-related or otherwise associated with the site or nearby properties.

E. Immediately before sampling, place the leak check compound at each location where ambient air could enter the sampling system or where cross contamination may occur. For liquid compounds (for example, isopropanol), wet a paper towel with the leak check compound and place the towel over each location where ambient air could enter the sampling system. These areas include: the base of the soil probe at ground surface, the connection from the soil gas probe to the sampling line, and any connections within the sampling line. Leak check compounds that are vapors require a device to hold the vapor near the test location (such as a cover at the surface). The type of device to be used must be specified in the soil gas sampling work plan.

F. The leak check compound must be included in the list of analytes looked for during laboratory analysis of each sample.

H.6.2. Detection of leak check compound.

A. If greater than 100 ug/m^3 of the leak check compound is detected in a sample, the following actions must be taken:

- Review the analytical results that show a detection of the leak check compound.
- If a review of the data indicates that the analytical data is accurate, evaluate the cause of the leak through system testing.
- Based on the concentration of the leak check compound detected, evaluate the impacts of the leak on sample collection and sample

integrity. Document the findings and the evaluation in the soil gas investigation report submitted to MDNR.

- In certain cases, MDNR will reject data in which a leak check compound has been detected at a concentration in excess of 100 ug/m^3. In such cases, resampling will generally be required.

H.7. Laboratory Analysis

H.7.1 Off-site and On-site Analysis.

A. Samples may be analyzed either off-site in a fixed laboratory or on-site in a mobile laboratory. On-site analyses can provide for a more timely indication of problems with sample system leaks or short-circuiting, thus allowing corrections to be made and resampling to occur while drilling and sampling equipment remains on the site. If samples are analyzed on-site, the probes from which the samples are collected should either be installed as permanent sampling points or clearly and durably marked so that sampling can be duplicated during subsequent gas sampling events. Procedures for on-site sampling and analysis must be clearly documented in the work plan submitted to MDNR and approved by MDNR prior to implementation.

H.7.2. Analyses Required.

A. Contaminants of concern ("COCs"): For petroleum product spills, COCs include benzene, toluene, xylenes, ethylbenzene, MTBE, and naphthalene.

B. Leak test compound.

C. The entity performing the work may also analyze vapor samples for oxygen, carbon dioxide, nitrogen, methane, and other indicators of the biodegradation of hydrocarbon vapors, though these analyses are not required. Of these, MDNR recommends analyzing for oxygen, at least. If samples for oxygen analysis are collected, the oxygen sample should be collected after the COC sample, as oxygen sampling requires the use of an oxygen meter and pump.

H.7.3. Analytical Methods.

A. Fixed laboratory analysis: Gas chromatograph by EPA Method TO-14A, TO-15, or an equivalent air analysis method. Summa canisters are required for these analytical methods. SW-846 Methods 8260B and 8021 may be used if detection limits below applicable target levels can be achieved. The soil gas sampling work plan submitted to MDNR for review and approval must specify the analytical methods to be used.

B. On-site laboratory analysis: Gas chromatography using SW-846 Methods 8260B or 8021. Method detection limits must be below applicable target levels. Other methods may be used only with prior approval of MDNR.

C. Selected laboratory analyses must meet detection limits that support site objectives (i.e., detection limits must be lower than applicable target levels).

D. Regardless of whether the analyses are conducted at an off-site, fixed laboratory or an on-site mobile laboratory, the laboratory must provide adequate and complete Quality Assurance and Quality Control (QA/QC) data for each analysis. QA/QC data should be developed in accordance with the provisions of the analytical method used or as stipulated in SW-846.

H.8. Documentation of Soil Gas Sampling Event.

H.8.1 Soil gas investigation report.

A. A soil gas investigation report that includes a discussion of field operations, deviations from the approved work plan, data inconsistencies, and other significant procedural and analytical details must be prepared and submitted to MDNR. The report should stand alone, though the document may be included as an attachment or appendix of a risk assessment report.

B. At a minimum, the soil gas investigation report must contain the following:

- A site plan map, a map identifying soil gas probe locations, and a map showing soil and groundwater contamination relative to the locations of the soil gas probes and any current or future structures.
- A site map on which soil gas concentration data has been plotted. The map must be at the same scale as the maps discussed above.
- A narrative description of probe installation and sampling procedures, including leak check testing.
- Analytical data summary tables.
- Laboratory data sheets.
- A table showing applicable target levels and appropriate documentation showing how the target levels were calculated.
- A narrative discussion of analytical results, including a comparison of soil gas sampling results to soil vapor target levels.
- Legible copies of field forms, logs, and associated notes pertinent to probe installation and soil gas sampling.
- As-built diagrams of probes or wells showing overall construction and depth of each sampling point.
- QA/QC data.
- Conclusions and recommendations.

References

American Petroleum Institute, 2004, *Soil Gas Sampling – Draft for Review Only*, July 16, 2004.

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Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division, 2004, *Draft Indoor Air Guidance*, September 2004.

Hartman, Blayne, 2002, How to Collect Reliable Soil-Gas Data for Risk-Based Applications, Part 1: Active Soil-Gas Method. *LUSTLine* Bulletin 42, October 2002.

Hartman, Blayne, 2004, How to Collect Reliable Soil-Gas Data for Risk-Based Applications – Specifically Vapor Intrusion, Part 3: Answers to Frequently Asked Questions. *LUSTLine* Bulletin 48, November 2004.

H&P Mobile Geochemistry, 2004, *Soil Vapor Standard Operating Procedures for Vapor Intrusion Applications*, June 2004.

H&P Mobile Geochemistry, 2004, *Vapor Monitoring Wells/Implants Standard Operating Procedures (for Vapor Intrusion Applications)*, August 2004.

U.S. Environmental Protection Agency, 2002, *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway From Groundwater and Soils (Subsurface Vapor Intrusion Guidance)*, November 2002.

APPENDIX I
FLEXIBILITY IN CALCULATION OF TIER 2 AND TIER 3 SITE-SPECIFIC TARGET LEVELS

For the MRBCA process, the acceptable risk levels are as follows:

<u>Carcinogenic Risk</u>

- The total risk for each chemical, which is the sum of risk for all complete routes of exposure for each chemical, must not exceed 1×10^{-5}.
- The cumulative site-wide risk (sum of risk for all chemicals and all complete routes of exposure) must not exceed 1×10^{-4}.

<u>Non-carcinogenic Risk</u>

- The hazard index for each chemical, which is the sum of hazard quotients for all complete routes of exposure for each chemical (the total risk), must not exceed 1.0.
- The site-wide hazard index, which is the sum of hazard quotients for all chemicals and all complete routes of exposure, must not exceed 1.0.

If the hazard index exceeds 1.0, the hazard index corresponding to a specific toxicological end point may be calculated by a qualified toxicologist. In this case, the specific hazard indices for each toxicological end point must be less than unity (1.0).

If any of these acceptable risk levels are exceeded, a risk management plan is necessary to reduce the concentrations to acceptable levels. These acceptable risk criteria can be satisfied in several different ways that provide considerable flexibility to the remediating party. Due to this flexibility, the remediating party can select the risk management plan that is optimal for site-specific conditions.

To illustrate the above flexibility, an example is presented below.

Consider the following site that has four chemicals and three complete routes of exposure. Exhibit 1 presents the representative concentrations for each chemical and each route of exposure used to estimate the risk presented in Exhibit 2.

Exhibit 1. Representative Concentrations for Each Chemical and Each Complete Route of Exposure

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	1.5	1.0	1.0
Chemical 2	0.5	0.75	1.0
Chemical 3	0.25	0.5	0.5
Chemical 4	0.20	0.25	5.0

Exhibit 2. Risk Calculated Using Representative Concentrations in Exhibit 1

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	1.1×10^{-5}	4.0×10^{-6}	5.0×10^{-6}	2.0×10^{-5}
Chemical 2	5.0×10^{-6}	7.5×10^{-6}	2.0×10^{-6}	1.45×10^{-5}
Chemical 3	5.0×10^{-6}	2.0×10^{-6}	5.0×10^{-7}	7.5×10^{-6}
Chemical 4	3.9×10^{-5}	2.2×10^{-5}	7.0×10^{-6}	6.8×10^{-5}
Cumulative Site-Wide Risk				**1.1×10^{-4}**

Note that the following acceptable risks are exceeded:

- Total risk for chemical 1,
- Total risk for chemical 2,
- Total risk for chemical 4, and
- Cumulative site-wide risk.

To meet the acceptable risk criteria, the remediating party may select any one of the following three options for the risk management plan.

Example 1

The concentration of each chemical may be reduced by a factor of 6.8. This will result in total risk of each below 1.0×10^{-5} and cumulative site-wide risk below1.0×10^{-4}. For this case the resulting cleanup levels and risks would be:

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	0.22	0.15	0.15
Chemical 2	0.07	0.11	0.15
Chemical 3	0.04	0.07	0.07
Chemical 4	0.03	0.04	0.74

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	1.62×10^{-6}	5.88×10^{-7}	7.35×10^{-7}	2.94×10^{-6}
Chemical 2	7.35×10^{-7}	1.10×10^{-6}	2.94×10^{-7}	2.13×10^{-6}
Chemical 3	7.35×10^{-7}	2.94×10^{-7}	7.35×10^{-8}	1.10×10^{-6}
Chemical 4	5.74×10^{-6}	3.24×10^{-6}	1.03×10^{-6}	1.00×10^{-5}
Cumulative Site-Wide Risk				**1.62×10^{-5}**

Example 2

Activity and Use Limitations (AULs) may be used to eliminate two of the complete routes of exposure, resulting in the following risks:

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	Eliminated	Eliminated	5.0×10^{-6}	5.0×10^{-6}
Chemical 2			2.0×10^{-6}	2.0×10^{-6}
Chemical 3			5.0×10^{-7}	5.0×10^{-7}
Chemical 4			7.0×10^{-6}	7.0×10^{-6}
Cumulative Risk				**1.45×10^{-5}**

In the above, both the total risk for each chemical and the cumulative site-wide risk are acceptable.

Example 3

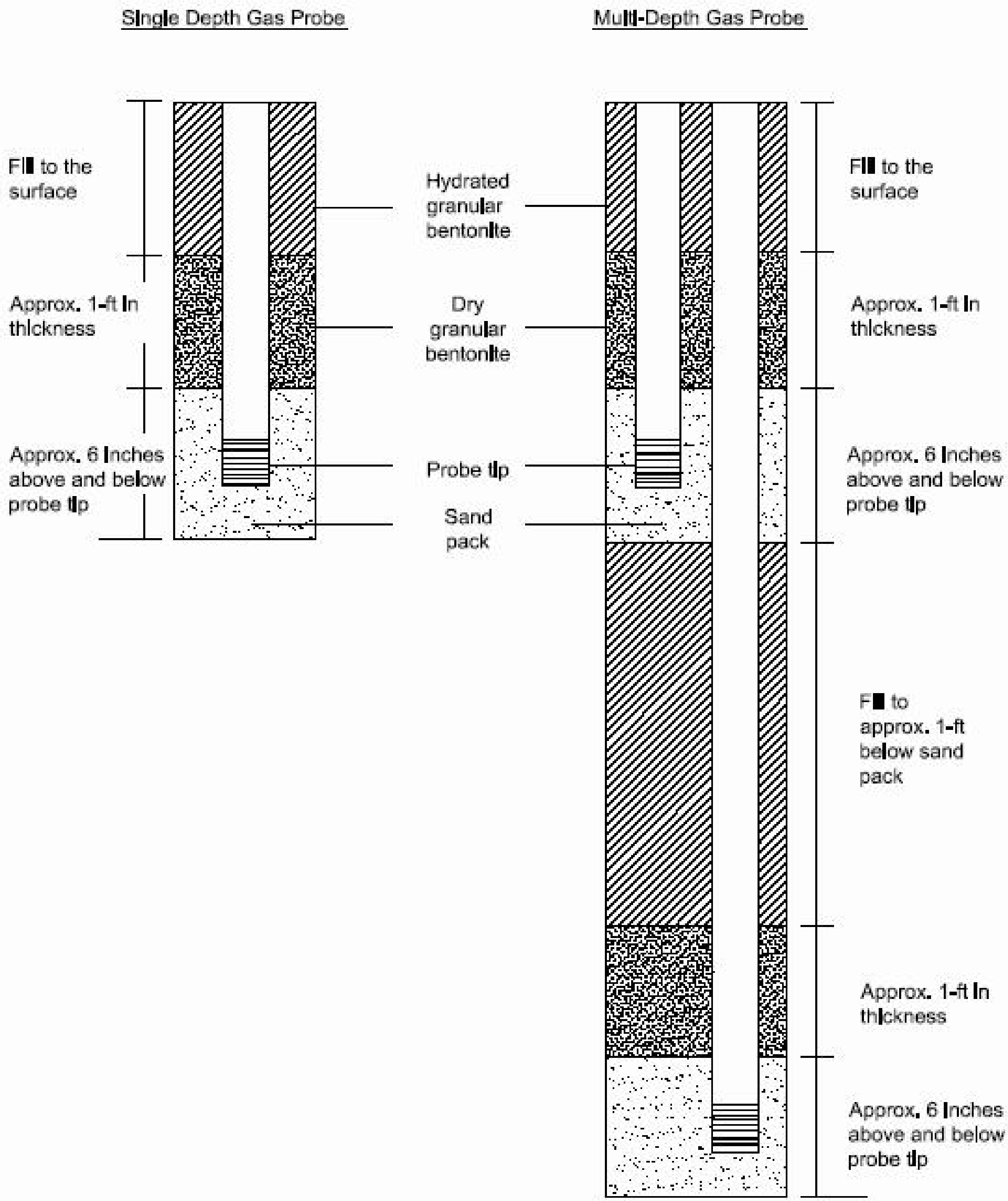
In this case the concentrations of different chemicals are reduced by different factors. For example, we could reduce the concentration of chemicals 1, 2 and 3 by a factor of 2 and reduce concentration of chemical 4 by a factor of 6.8. This would result in the following cleanup levels and risk:

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	0.75	0.5	0.5
Chemical 2	0.25	0.375	0.5
Chemical 3	0.125	0.25	0.25
Chemical 4	0.029	0.037	0.74

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	5.5×10^{-6}	2.0×10^{-6}	2.5×10^{-6}	1.0×10^{-5}
Chemical 2	2.5×10^{-6}	3.75×10^{-6}	1.0×10^{-6}	7.25×10^{-6}
Chemical 3	2.5×10^{-6}	1.0×10^{-6}	2.5×10^{-7}	3.75×10^{-6}
Chemical 4	5.74×10^{-6}	3.24×10^{-6}	1.03×10^{-7}	1.0×10^{-5}
Cumulative Risk				**3.1×10^{-5}**

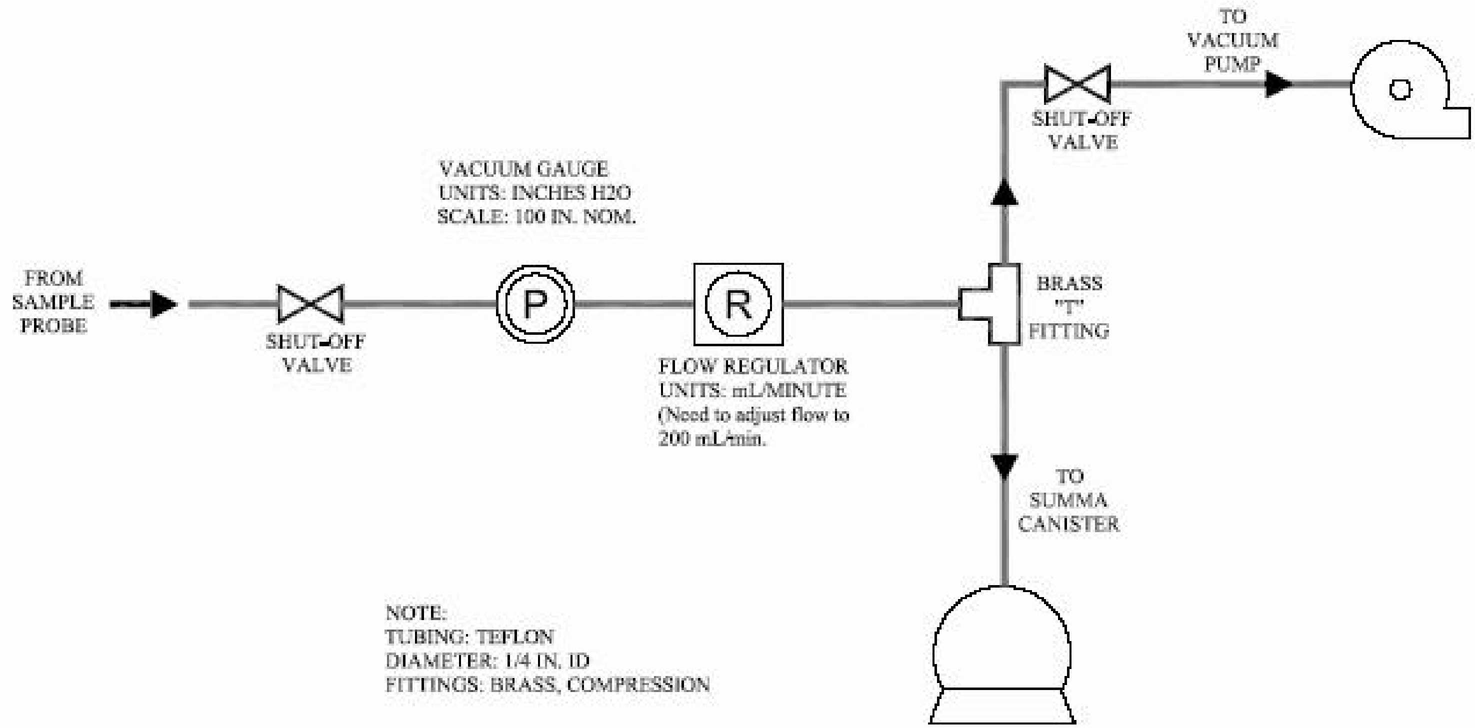
In this case the cumulative risk at the site is equal to 3.1×10^{-5} and it is therefore below acceptable risk levels.

The example above illustrates a case where a selected remedial technology reduces the site-specific concentrations of different chemicals by different amounts. For example, soil vapor extraction, depending on the volatility of chemical, would reduce the concentrations of the volatile chemicals by different amounts.



TITLE:

FIGURE 1
SOIL GAS PROBE CONSTRUCTION DIAGRAM



TITLE:

FIGURE 2
EXAMPLE SOIL GAS SAMPLING PLAN

Figure 3
Example Soil Gas Sampling Form

Date		Sampler	
Client		Project#:	
Container Type:		Container ID:	
Sample ID:			
Weather Conditions:	Temperature:	Precipitation:	
Sampling Device:			
Purge Start Time:		End Time:	
Sample Start Time:		End Time:	
Canister start pressure:		End pressure:	
Volume gas extracted:			

Field Measurements

Time	Flow (mL/min)	Pressure (in H20)	Comments

Comments:

APPENDIX J
APPENDIX TO SECTION 11 LONG-TERM STEWARDSHIP FOR RISK-BASED REMEDIATION SITES

APPENDIX J-1
MODEL DECLARATION OF RESTRICTIVE COVENANT AND GRANT OF ACCESS

The following Model Restrictive Covenant and Grant of Access model document is to be used when response activities have been approved by MDNR and should not be used if MDNR has not approved the response activities. The final format of this document should comply with appropriate state and local recording requirements to facilitate recordation by the County Recorder of Deeds.

MODEL DECLARATION OF RESTRICTIVE COVENANT AND GRANT OF ACCESS

This Restrictive Covenant and Grant of Access has been recorded with the _________________ County Recorder of Deeds for the purpose of protecting public health, safety, and welfare, and the environment by prohibiting or restricting activities that could result in unacceptable exposure to environmental contamination present at the property located at [insert location of property in city and county] and legally described in Exhibit A hereto ("Property"). Any portion of the Property that is not subject to activity or land use restrictions is identified and distinguished by legal description and survey in Exhibit A-1.

Pursuant to an Agreement between the department and the Remediating Party, the Remediating Party implemented certain response activities at the Property approved by MDNR. These activities are briefly described herein and fully described in documents available from MDNR, a political subdivision of the State of Missouri, having a mailing address of P.O. Box 176, Jefferson City, Missouri 65102.

This Restrictive Covenant and Grant of Access with the ______________ County Recorder of Deeds in order to:

[Insert appropriate description of purpose from "Model Paragraphs for Use in Restrictive Covenant," part 1, Purpose(s) of Restrictive Covenant. Note: the Model Paragraphs may be modified as appropriate for the Property.]

Summary of Response Activities.

[Insert a paragraph that briefly describes the response activities which have been conducted i.e. soil removal to remediate xyz contaminants in whatever area of the site; placement of engineered cap; remediation of groundwater; asbestos or lead paint abatement, etc., and how the response activities address unacceptable risk for all relevant pathways that require restrictions]

MDNR recommends that prospective purchasers or users of the Property

undertake appropriate due diligence prior to acquiring or using this Property.

NOW THEREFORE,

Restrictions and Conditions

(**insert name of property owner), (insert mailing address of owner)** (hereinafter referred to as the "Owner"), hereby declares and covenants that the Property shall be subject to the following restrictions and conditions:

1. **Restrictions Applicable to the Property**. The following restrictions and duties apply to the property and shall be the responsibility of the owner:

   [insert appropriate restrictions based on the attached "Model Paragraphs for Use in Restrictive Covenants," part 2, "Restrictions." The Model Paragraphs may be modified as appropriate for each Property in negotiations with MDNR.]

   [IF USER DESIRES ANY USAGES TO BE SPECIFICALLY ALLOWED, INCLUDE HERE USING A STATEMENT: "THESE RESTRICTIONS DO NOT PREVENT . . ."]

   [Note: mandatory activities to ensure site integrity should be added here.]

   [Note: Maintenance and inspection responsibilities should be set out either here or in the Risk Management Plan.]

   [Note: Any limitations on alteration of the Property should be set out here.]

2. **Contaminated Soil Management.** The Owner shall manage all soils, media and/or debris located on the Property in accordance with the applicable requirements of Missouri and federal law.

3. **Grant of Access to the department**. Owner hereby grants and conveys to the department, its agents, contractors, and employees, and to any person performing pollution remediation activities under the direction thereof, access at reasonable times to the Property to determine and monitor compliance with the Risk Management Plan and perform such investigations and actions as the department deems necessary to ensure that use, occupancy, and activities of and at the Property are consistent with this Restrictive Covenant; ensure that any remediation implemented complies with state law; perform any additional investigations or remediation deemed necessary to maintain compliance with the approved Risk Management Plan; and ensure the structural integrity and continued effectiveness of any engineering controls (if appropriate) described in this Restrictive Covenant and Grant of Access.

4. **Notice to Lessees and Other Holders of Interest in the Property**. Owner, or

any future holder of any interest in the Property, shall cause any lease, grant, or other transfer of any interest in the Property to include a provision expressly requiring the lessee or transferee to comply with this Restrictive Covenant and Grant of Access. The failure to include such provision shall not affect the validity or applicability to the Property of this Restrictive Covenant and Grant of Access.

5. **Enforceability of Restrictions; Persons Entitled to Enforce Restrictions**. This Restrictive Covenant shall run with the land and shall be binding on the Owner, future Owners, heirs, successors, lessees, or assigns and their authorized agents, employees or persons acting under their direction or control. This Restrictive Covenant shall be enforceable in an appropriate Court by Owner and/or by the department, their successors, transferees, and assigns. Owner agrees that the restrictions are enforceable, and agrees not to challenge the appropriate circuit court's jurisdiction. The State of Missouri, through MDNR, may enforce the restrictions set forth in the Restrictive Covenant by legal action in a court of competent jurisdiction.

6. **Written Notice of Property Conveyance Required.** The Owner shall provide written notice to the Director of the department, of the intent to transfer an interest in the Property not less than 14 days prior to the expected date of transfer. This notice shall include the name and business address of the transferee and the expected date of transfer. This provision does not supercede other property transfer notices and related provisions under state and federal laws and regulations (e.g., RCRA, CERCLA, etc.) and associated administrative mechanisms such as permits, orders or other agreements. Please check with project manager for program-specific requirements.

7. **Property Conveyance – Continuance of Provisions.** The Owner shall not convey any title, access, or other interest in the Property without providing notice to those acquiring the interest of the continued implementation, operation, and maintenance of any remedial action that has been implemented on the Property and requiring along with the interest the prevention of the releases and exposures described above.

8. **Severability.** If any provision of this Restrictive Covenant and Grant of Access is held invalid by any Court of competent jurisdiction, invalidity of any such provision shall not affect the validity of any other provisions hereof. Also, such provisions shall continue unimpaired in full force and effect.

9. **Amending, Modifying, or Rescinding the Restrictive Covenant.** This Restrictive Covenant and Grant of Access shall not be amended, modified or terminated except by a written instrument executed by and between the Owner at the time of the proposed amendment, modification, or termination and the department. Within five (5) days of executing an amendment, modification, or termination of this Restrictive Covenant and Grant of Access, the Owner shall record such amendment, modification, or termination, on the appropriate form

provided by the department, with the _________ County Recorder of Deeds, and within five (5) days thereafter, the Owner shall provide a true copy of the recorded amendment, modification, or termination to the department.

10. **Disputes.** Any disputes regarding provisions of this covenant that cannot be resolved by the department and the property owner will be addressed pursuant to the [rule].

11. **Institutional Control Contract.** The department's Hazardous Waste Program requires that owners of property for which a Restrictive Covenant and Grant of Access is required enter into an Institutional Control Contract with the department. Said Contract is attached hereto as Exhibit B and by this reference made a part hereof.

12. **Authority to Execute Restrictive Covenant.** The undersigned person executing this Restrictive Covenant and Grant of Access is the Owner, or has the express written permission of the Owner and represents and certifies that he or she is duly authorized and has been empowered to execute and deliver this Restrictive Covenant and Grant of Access.

SIGNATURES

The undersigned property owner or person executing this Restrictive Covenant and Grant of Access on behalf of the Owner represents and certifies that they are truly authorized and have been fully empowered to execute and deliver this Restrictive Covenant and Grant of Access.

STATE OF MISSOURI)
) SS
COUNTY OF)

Property owner(s) or authorized representative(s) thereof

Type or Print: Signature _______________________ Date:

Type or Print: Signature _______________________ Date:

IN WITNESS WHEREOF, the Owner(s) or Owner's authorized representative(s) of the above-described Property has caused this Restrictive Covenant and Grant of Access to be executed on this _______ day of _______________, 20____. Signed in the presence of Property Owner/Authorized Representative subscribed and acknowledged.

Subscribed and acknowledged before me this _____ day of ___________, 20___.

Notary Public

My commission expires ________________________.

MODEL PARAGRAPHS FOR USE IN RESTRICTIVE COVENANT

1. Purpose(s) of Restrictive Covenant

Insert one or more of the following as applicable at section 1 of the restrictive covenant. Specific language in these model paragraphs may be negotiated with MDNR for each Property.

A. That the Property is used in a manner consistent with the risk assessment and resulting risk-based remediation standards for the Property, which assessment has either been approved by the department in coordination with the Missouri Department of Health and Senior Services or EPA.
B. That groundwater at the Property is not used [at all or for domestic uses such as drinking or bathing].
C. That humans are not exposed to soils at the Property contaminated with substances in concentrations exceeding the levels established in the Risk Management Plan for the Property.
D. That storm water or water of other origin does not infiltrate soils at the Property contaminated with substances in concentrations exceeding the pollutant mobility criteria established by the department.
E. That Buildings are not constructed over soils [or ground water] at the Property contaminated with substances in concentrations exceeding the volatilization criteria established by the department [or that may potentially lead to formation of unacceptable risk-based levels of vapors inside such buildings] (defined with plat).
F. That the engineered control(s) described herein are not disturbed and are properly maintained to prevent human and ecological exposure to soils at the Property contaminated with substances in concentrations exceeding the levels established in the RMP and/or risk assessment for the Property.
G. Other (as circumstances require).

2. Restrictions

Specific language in these model paragraphs may be negotiated with MDNR for each Property. Restrictions fall into several categories including land use, groundwater, disturbance, and construction. Depending on site-specific conditions, restrictions other than those listed here may be appropriate, and will be negotiated between the property owner and the department. Be specific in describing relevant or existing ordinances, statewide restrictions and/or local zoning if these AULs are being relied upon in any way as part of the RMP.

USE RESTRICTIONS:

A. Nonresidential Use or Construction Worker Use (reference specific zoning ordinances)**:** The Property currently meets the department standards for restricted nonresidential or construction worker use and, based on reports on file at the department offices in Jefferson City, Missouri, the contaminants present pose no unacceptable present or future risk to human health or the environment based on restricted use of the Property. No further response action for the Property is required by the department as long as the Property is not to be used for residential or other purposes constituting unrestricted use. The Property shall not be used for purposes other than nonresidential or construction worker uses. If any owner desires in the future to use the Property for residential or other purposes constituting unrestricted use, the department must be notified 120 days in advance and further analyses and, as necessary, response action(s) will be required prior to such use. The Property may not be used in a manner that conflicts with this restriction.

B. **Nonresidential Use With Engineered Controls** (reference specific zoning ordinances)**:** The Property currently meets the department standards for restricted nonresidential or construction worker uses and, based on reports on file at the department offices in Jefferson City, Missouri, the contaminants present pose no unacceptable present or future risk to human health or the environment based on restricted nonresidential or construction worker uses of the Property. The department requires no further response action for the Property as long as the Property is not used for residential or other purposes constituting unrestricted use. The Property is protective for restricted commercial or industrial uses as long as the **(insert engineering or other physical controls in place)** is/are maintained to prevent exposure. If any owner desires in the future to use the Property for residential or other purposes constituting unrestricted use, the department must be notified 120 days in advance and further analyses and, as necessary, response actions will be required prior to such use. The Property may not be used in a manner that conflicts with this restriction.

GROUNDWATER RESTRICTIONS:

C. **No Drilling or Use of Groundwater: The** groundwater beneath the Property contains contaminants at concentrations exceeding applicable risk-based standards. The owner of the Property shall prevent: use of and exposure to the groundwater; any artificial penetration of the groundwater-bearing unit(s) containing contaminants that could result in cross-contamination of clean groundwater-bearing units; installation of any new groundwater wells on the Property, except those used for investigative purposes; use of groundwater for drinking or other domestic purposes and the use of groundwater for purposes other than domestic purposes; release of groundwater to surface water bodies, whether such release is the result of human activities or is naturally occurring. Should a release of contaminated groundwater occur, the owner must take action to contain and properly dispose of such groundwater. [OPTIONAL IF NEEDED: Groundwater beneath the Property shall be monitored by the owner in accordance with specific requirements of the department-approved monitoring plan unless or until the department approves any modifications].

D. **No Drilling or Use of Groundwater; Engineered Controls for Groundwater: The** groundwater beneath the Property contains contaminants identified in reports on file at the department offices in Jefferson City, Missouri at concentrations that exceed the risk-based standards of the department, and **(insert physical or engineering controls)** have been constructed in the area located on the map attached as **"Exhibit ( )."** The physical or engineering controls must remain in place and effective in accordance with the department-approved **(insert name of plan)** unless or until the department approves any modifications. Additionally, the owner of the Property must prevent: use of and exposure to the groundwater; any artificial penetration of the groundwater-bearing unit(s) containing contaminants which could result in cross-contamination of clean groundwater-bearing units; the installation of any new groundwater wells on the Property, except those used for investigative purposes; the use of groundwater for drinking or other domestic purposes and the use of groundwater for purposes other than domestic purposes; and release of groundwater to surface water bodies, whether such release is the result of anthropogenic activities or is naturally occurring. Should a release of contaminated groundwater occur, the owner must take action to contain and properly dispose of such groundwater. [Groundwater beneath the Property shall be monitored by the owner in accordance with specific requirements of the department-approved monitoring plan unless or until the department approves any modifications].

DISTURBANCE RESTRICTIONS:

E. **No Disturbance of Soil: Soil** at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department's risk-based standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, soil at the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** shall not be excavated or otherwise disturbed in any manner without the written permission of the department. Should the owner desire to disturb soil at the Property **[in one or more of the areas shown on the map at Exhibit ( ) attached hereto]**, the owner shall request approval to do so from the department at least 30 days before the soil disturbance activities are to begin. Based on the potential hazards associated with the soil disturbance activities, the department may deny the request to disturb the soils or may require specific protective or remedial actions before allowing such soil disturbance activities to occur. This requirement does not supercede other state and federal requirements, and may require other permits (e.g., water protection land disturbance).

F. **Disturbance of Soil Permitted Under Approved Soil Management Plan:** Soil at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department's risk-based standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, soil at the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** shall not be excavated or otherwise disturbed in any manner unless under the provisions of the department-approved Soil Management Plan attached hereto as Exhibit ____.

CONSTRUCTION RESTRICTIONS:

G. Soil at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department's risk-based standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, no buildings may be constructed on the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** except with the written approval of the department. Should the owner desire to construct a building on the Property **[in one or more of the areas shown on the map at Exhibit ( ) attached hereto]**, the owner shall request permission to do so from the department at least 30 days before construction is anticipated to begin. Based on the potential hazards associated with the construction activities, the department may deny the request to construct or may require specific protective or remedial actions before allowing such construction activities to occur.

APPENDIX J-2
MODEL ORDINANCE FOR USE IN LONG-TERM STEWARDSHIP OF CONTAMINATED SITES WHEN GROUNDWATER CONTAMINATION IS PRESENT

Regulations setting forth procedures for determining risk-based remediation objectives may allow higher amounts of soil and/or groundwater contamination to remain in place where activity and use limitations (legal barriers to access) are established. Local ordinances prohibiting the use of groundwater for potable or other purposes and prohibiting the installation and use of new water supply wells are one type of control. Ordinances suitable for use as an effective control may serve as a part of a remediation plan, and they may demonstrate that contaminants of concern in soil and groundwater will meet applicable cleanup criteria. Ordinances also may be relied upon to exclude the groundwater ingestion exposure route from further consideration. Where there are no existing wells and where future uses of groundwater are prohibited, it is unnecessary to remediate contamination to levels based on domestic uses of groundwater.

To be recognized as part of a site remediation plan, an ordinance must provide a free-standing, self-contained enforceable legal barrier to contamination. It does not rely on any further action by local officials to be implemented, and those officials will be available for enforcement as necessary. The ordinance must effectively prohibit the installation and use of water wells.

Following is a model ordinance that satisfies the regulatory requirements for ordinances used to manage contaminants left in place above unrestricted use levels. Changes from this form may be allowed for specific local government conditions; however the basic requirements of the ordinance must be included and unencumbered. Local governments should assess their current and future water supply needs and resources before deciding whether the use of such ordinances is consistent with the long-range public water supply plan.

ORDINANCE NUMBER ________

AN ORDINANCE PROHIBITING THE USE OF GROUNDWATER AS A POTABLE WATER SUPPLY BY THE INSTALLATION OR USE OF POTABLE WATER SUPPLY WELLS OR BY ANY OTHER METHOD

WHEREAS, certain properties in the [City/County] of _______________, Missouri have been used over a period of time for commercial/industrial purposes; and

WHEREAS, because of said use, concentrations of certain chemical constituents in the groundwater beneath the [City/County] may exceed groundwater quality standards for drinking water or other uses described in Missouri water quality standards 10 CSR 20-7.031 or other criteria established as risk-based remediation cleanup standards described in Missouri's Departmental Risk-Based Corrective Action Technical Guidance or any applicable rules and regulations; and

WHEREAS, the [City/County] of _______________ desires to limit potential threats to human health, public welfare and the environment from groundwater contamination while facilitating the redevelopment and productive use of properties that are the source of said chemical constituents;

NOW, THEREFORE, BE IT ORDAINED BY THE [CITY COUNCIL/COUNTY COMMISSION] OF THE [CITY/COUNTY] OF ______________________, MISSOURI:

Section One. Prohibitions.
The use of groundwater as a potable water supply is prohibited. The use or attempt to use groundwater from within the corporate limits of the [City/County] of ___________________ by the operation, installation or drilling of wells or by any other method is hereby prohibited. The [City/County] of ________________] may operate existing groundwater wells if authorized through a Memorandum of Agreement described in Section Four.

Section Two. Penalties and Injunctive Relief.
Any person violating the provisions of this ordinance shall be subject to a fine of up to ___________ for each violation. Any person that violates this ordinance must close the well within thirty (30) days by methods specified in regulation by the state. The city/county will close any well that is not closed within thirty (30) days, and may recover the costs of completing the closure from the owner of the property on which the well is located.

Section Three. Definitions.
"Person" is any individual, partnership, co-partnership, firm, company, limited liability company, corporation, association, joint stock company, trust, estate, political subdivision, or any other legal entity, or their legal representatives, agents or assigns.

Section Four. Memorandum of Agreement.
The [Mayor/Commission] of the [City/County] of ______________________ is hereby authorized and directed to enter into a Memorandum of Agreement with the Missouri Department of Natural Resources (department) for tracking remediated sites and notifying the department of changes to this ordinance.

Section Five. Repealer.
All ordinances or parts of ordinances in conflict with this ordinance are hereby repealed insofar as they are in conflict with this ordinance.

Section Six. Severability.
If any provision of this ordinance or its application to any person or under any circumstances is adjudged invalid, such adjudication shall not affect the validity of the ordinance as a whole or of any portion not adjudged invalid.

Section Seven. Effective date.
This ordinance shall be in full force and effect from and after its passage, approval and publication as required by law.

ADOPTED: _________________ _______________________________________
(Date) (City Clerk)

APPROVED: ________________ _______________________________________
(Date) (Mayor)

Officially published this ______ day of _________________, 20___.

APPENDIX J-3
INSTITUTIONAL CONTROL CONTRACT

______________________ has entered into a Letter of Agreement pursuant to the [specific authority for cleanup Program, citing statute], with the Missouri Department of Natural Resources (the department) for (name of facility or site, hereafter "site"), a site of environmental contamination located at (address of facility or site) in the city (town, village) of____________, ___________ County, Missouri.

The site has been remediated to a level safe for its current or intended use as specified in the department-approved risk management plan provided that certain risk reduction and exposure control measures remain in place. The department has an obligation to protect human health and the environment and to assure that all of the risk reduction and exposure control measures in the risk management plan (and any amendments thereto) remain intact, functional, and able to serve their intended purposes.

NOW THEREFORE, [insert name of Property owner], [insert mailing address of owner], (hereafter referred to as the "Owner") hereby agrees that:

1. The Owner shall pay to the department a one-time fee of $__________ to be used to fund regular inspections of the risk reduction and exposure control measures implemented at the site for as long as necessary.

2. The Owner agrees to execute and file with the ____________ County Recorder of Deeds a Restrictive Covenant and Grant of Access pertaining to restrictions of property usage and management of the contamination.

3. The Owner shall file this Agreement and the Restrictive Covenant and Grant of Access with the _______________ County Recorder of Deeds within five (5) days of execution of this Agreement and provide to the department evidence of such recording, to include a true copy of the documents as filed and stamped by the _____________ County Recorder of Deeds.

4. A copy of the Letter of Completion shall be filed by the Owner with the _________ County Recorder of Deeds in the chain of title for this property. If the department determines that the Owner has failed to comply with the terms of this Agreement or the Restrictive Covenant and Grant of Access or fails to comply with the terms of the Letter of Completion or fails to comply with the department-approved risk management plan, the Letter of Completion as provided by the department pertaining to this site may be rescinded and deemed null and void at the discretion of the department. In this event, a notice shall be filed in the property chain of title by the department with the ___________ County Recorder of Deeds. This notice shall be attached to a copy of the Letter of Completion Letter.

The undersigned person executing this Agreement on behalf of the Owner represents and certifies that he or she is duly authorized and have been fully empowered to execute and deliver this Agreement.

IN WITNESS WHEREOF, the Owner of the site has caused this Agreement to be executed on this _________ day of ______________, 20___.
Signed in the presence of Property Owner subscribed and acknowledged.

Signature of Owner

Subscribed and acknowledged before me this ____ day of _______________, 20____.

____
Notary Public

My commission expires ____________________________.

IN WITNESS WHEREOF, the Missouri Department of Natural Resources has caused this Agreement to be executed on this _____________ day of _______________, 20____.

Signed in the presence of the Missouri Department of Natural Resources subscribed and acknowledged.

____
Director
Hazardous Waste Program
Missouri Department of Natural Resources

Subscribed and acknowledged before me this _______ day of ___________, 20_____.

____
Notary Public

My commission expires ______________________________.

APPENDIX J-4
MODEL NOTIFICATION LETTER

Letter template for use by site owner/operator or remediation applicant to satisfy the requirements of the [rule]:

NOTICE

[Date]

[Address]

Dear *[Adjacent Property Owner] [Unit of Local Government]*:

[Name of person or entity performing remediation] is performing an environmental response action at [*name and physical address of site (not a P.O. Box)]*. The response action is being performed because *[state the nature of the release]*. The response action consists of *[describe the nature of the response action]*.

To protect human health, public welfare and the environment, Missouri regulations require that *[name of person or entity performing remediation]* either clean up the site, including groundwater contamination, or demonstrate that the groundwater in the area of the release will not be used as potable water. ("Groundwater" is the water beneath the ground stored in the pores of soil and rock; some communities and homeowners pump this water out of wells to supply potable water. "Potable" means fit for human consumption including drinking, bathing, preparing food, washing dishes, and so forth.) The *[name of unit of local government, address]* has an ordinance prohibiting the use of groundwater for potable water. Under Missouri regulations, local ordinances that effectively prohibit use of existing potable water supply wells, and the installation and use of new potable water supply wells may use those ordinances to support groundwater remediation objectives ([rule]). The Missouri Department of Natural Resources ("the department") has determined that the ordinance adopted by *[name of unit of local government]* meets the regulatory requirements. This ordinance has been used by the department in reviewing *[name of person or entity performing remediation]* in support of the remediation objectives as part of this response action.

Your property, *[legal description or reference to a plat showing boundaries],* is included in the area affected by the ordinance. This means that you cannot install or use a private, potable water well on your property. Based on the remediation objectives established in reliance on this ordinance, groundwater beneath your property may not be suitable for human consumption due to existing contamination. Missouri regulations require that you be notified of these facts. The ordinance may be found at *[citation to unit of local government's municipal code]*. If you wish to obtain a copy of the ordinance, please contact *[unit of local government, address and phone number]*.

To learn more about *[name of site]*, please contact either *[name of contact person, address and phone number]*, or the Missouri Department of Natural Resources, Hazardous Waste Program project manager, *[assigned project manager, address and phone number]*. You may also obtain a copy of the complete department file on *[name of site]*. To do so, you will need to submit a written request with your signature to the [Custodian of Records], Missouri Department of Natural Resources, Hazardous Waste Program, P.O. Box 176, Jefferson City, MO 65102. When you request a copy of the file, please reference the file heading shown below:
[Missouri Inventory Number/County
Site Name/City
Site Address
Agency Site Number]

Sincerely,

[Name of person or entity performing remediation]

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As discussed in Section 6.2, the department operates under its Quality Management Plan when collecting or overseeing the collection of environmental sampling data. This plan requires that:

> Each DEQ and DGLS program which generates environmental data will develop a Quality Assurance Project Plan (QAPP) following the current version of *Requirements for Quality Assurance Project Plans* (EPA QA/R-5) and will ensure that adequate resources (both monetary and staff) are provided to support the QA effort, and will be responsible for implementation of the QAPP. It will be the responsibility of the DEQ or DGLS program to ensure that QAPPs or other appropriate quality management tools are developed by any subgrantees, contractors, or, in some cases, the regulated community, who generate environmental data. For examples, sites undergoing corrective action under RCRA are typically required to have QAPPs… (pp. 3-4).
>
> And:
>
> …the Quality Management Plan (QMP) for Missouri…covers all intramural and extramural monitoring and measurement activities that generate and process environmental data for use by the MDNR-DEQ/DGLS. (p. 2).

A copy of the Quality Management Plan is available from the department or from the department's web site. EPA QA/R-5 contains further guidance on the details required to ensure data quality in field measurements. In addition, the department has developed generic QAPPs for use in project management. These generic QAPPs are also available from the department's web site.

K.1. MINIMUM SUBJECT AREAS

In order to meet the requirements of the department's Quality Management Plan, this appendix outlines the minimum subject areas that need to be addressed to meet quality assurance/quality control requirements for environmental measurement data that is collected as part of the MRBCA process. These minimum requirements include the necessary components for Work Plans submitted for department approval to conduct environment data collection and the necessary QA/QC documentation to be submitted after data collection.

I. Work Plans for Site Characterization
   - A. Sampling and Analysis Plan
   - B. Field Sampling Plan
   - C. Quality Assurance Project Plan
   - D. Health and Safety Plan

II Characterization Reports including Tier 1, Tier 2 and Tier 3 Risk Assessment Reports

A. Field QA/QC documentation requirements
B. Laboratory QA/QC documentation requirements

III Risk Management Plan

If the Risk Management Plan involves environmental data collection such as further site characterization, confirmatory samples following remedial activities or monitoring then:

A. Sampling and Analysis Plan
B. Field Sampling Plan
C. Quality Assurance Project Plan
D. Documentation of the Health and Safety Plan

If the Risk Management Plan does not involve sampling but only LTS and AUL etc. then data QA/QC would not be a component.

IV Completion of Risk Management Plan

This is covered in Section 12 but if the Risk Management Plan involves sampling then:

A. Field QA/QC documentation requirements
B. Laboratory QA/QC documentation requirements

K.2. QA/QC DOCUMENTATION REQUIREMENTS

With respect to II – A. above, the following details must be considered in field QA/QC planning and documentation:

- Calibration and maintenance records for field instrumentation,
- Documentation of sample collection procedures,
- Reporting of any variances made in the field to sampling plans, SOPs or other applicable guidance documents,
- Reporting of all field analysis results,
- Documentation of sample custody (provide copies of Chain-of-Custody documents),
- Documentation of sample preservation, handling and transportation procedures,
- Documentation of field decontamination procedures (and if applicable, collection and analysis of equipment rinsate blanks),
- Collection and analysis of all required duplicate, replicate, background and trip blank samples, and
- Documentation of disposal of investigation-derived wastes.

With respect to II – B. above, laboratory analytical data must be accompanied by QA/QC sample results. The following details must be considered in laboratory QA/QC planning and documentation:

- If the published analytical method used specifies QA/QC requirements within the method, those requirements must be met and the QA/QC data reported with the sample results.
- At a minimum, QA/QC samples must consist of the following items (where applicable):
    - Method/instrument blank,
    - Extraction/digestion blank,
    - Initial calibration information,
    - Initial calibration verification,
    - Continuing calibration verification,
    - Laboratory fortified blanks/laboratory control samples,
    - Duplicates, and
    - Matrix spikes/matrix spike duplicates,
- Documentation of appropriate instrument performance data such as internal standard and surrogate recovery.

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7Q10: The average minimum flow of a stream for seven consecutive days that has a probable recurrence interval of once-in-ten years.

Activity and Use Limitations (AULs): Mechanisms or controls that ensure that exposure pathways to COCs, through current or reasonable future uses, are not completed for as long as the COCs pose an unacceptable risk to human health, public welfare or the environment.

Acute water quality criterion for the protection of aquatic life: The highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1 hour) without harmful effects. Acute criteria apply to unclassified waters and to classified waters at the edge of the zone of initial dilution.

Additivity of risk: Sum of risk for each chemical.

Chronic water quality criterion for the protection of aquatic life: The highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without harmful effects. Chronic criteria apply to classified waters only at the edge of the mixing zone.

Cumulative site-wide risk: Sum of risk for all chemicals.

Dilution Attenuation Factor (DAF): Represents the reduction in the source concentration due to the influence of natural attenuation processes as a chemical migrates through the media.

Domestic use of groundwater: Ingestion, dermal contact, and inhalation of vapors generated by indoor water use activities such as showering and washing.

Exposure domain: Contaminated area that can result in exposure to a particular receptor by a specified route of exposure.

Exposure Pathway: The course a chemical takes from a source to the receptor. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also is included. The exposure pathway is considered complete if there are no discontinuities in or impediments to movement from the source of the contaminant to the receptor.

Habitat: A place where an ecological receptor such as an animal or plant normally lives.

Hydraulic conductivity: The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hyporheic zone: Region beneath and adjacent to streams and rivers where surface and groundwater mix.

Long-term stewardship: An appropriate system of controls, institutions and information necessary to fully protect human health, public welfare and the environment into perpetuity.

Mixing zone: An area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met [10 CSR 20-7.031(1)(N)].

Off-site: Areas beyond the site that potentially become contaminated.

Practical Quantitation Limit: Lowest concentration that can be reliably quantified within specified limits of precision and accuracy during routine laboratory operating conditions.

Receptor: An organism that receives, may receive, or has received exposure to a COC as a result of a release. Under the MRBCA program, human receptor refers to a resident child, resident adult, non-resident adult, or construction worker.

Remediating party: All private entities and their designees, collectively and generically, such as responsible parties, development interests, landowners and others directly involved in the remediation of a particular contaminated site.

Route of Exposure: The manner or mechanism by which a COC affects a receptor, for example, ingestion or inhalation.

Sensitivity Analysis: Evaluation of the calculated risk or target levels for different alternatives of possible input parameters.

Site: Areal extent of contamination.

Surficial soil: From 0-3 feet below ground surface (bgs).

Subsurface soil: From 3 feet bgs to the water table.

Tentatively Identified Compound (TIC): A compound in the chromatogram of a mass spectrometry method identified solely by computer comparison to a mass spectral reference library. The identity of the compound is not based on a comparison to any compounds for which the method has been calibrated.

Unrestricted use levels: Chemical concentrations at which soil and groundwater at a site are safe for residential land use and domestic use of groundwater.

M.1. INTRODUCTION

"Site-specific background concentration" can be defined as the ambient concentration of a chemical in soil or ground water in the immediate area of a site. Background concentrations can be naturally occurring (i.e., the concentration is not due to a release of chemicals from human activities), or anthropogenic (i.e., the concentration of a chemical in the environment is due to human activities, but is not the result of site-specific use or release of waste or products, or industrial activity).

Naturally occurring metals and other compounds are found in natural soils and ground water at varying concentrations. The presence of naturally occurring metals and other compounds in soil and groundwater is a direct function of its original natural composition. Over time, the concentration of naturally occurring metals in soil and groundwater will be influenced by geomorphologic processes such as erosion, weathering, and dissolution of mineral deposits.

Anthropogenic "background" concentrations of chemicals in the environment result from many human activities. For example, lead from automobile emissions, arsenic from use of defoliants, petroleum compounds from automobile and equipment leaks, pesticides/herbicides from agricultural practices, and poly-nuclear aromatic hydrocarbons from combustion of hydrocarbons. Widespread, ambient anthropogenic impacts typically result from the use of a product in its intended manner and may be present at generally low levels over large areas.

Natural and anthropogenic chemicals may be present in soil and groundwater in addition to those chemicals that are the result of on-site activities at contaminated sites. The chemical screening and remediation strategy (including implementation of institutional controls) for such sites often necessitates that background concentrations of chemicals be determined in order to ascertain the extent to which the contamination can be attributed to on-site activities.

The determination of 'background' concentrations of chemicals poses fundamental technical challenges. Background concentrations will be inherently variable resulting in a distribution or a range of concentrations that vary with the spatial distribution of the samples. This variability is rooted largely in the heterogeneous nature of soil and groundwater. Defining a single, representative site-specific background concentration for a chemical compound. Further, at sites where the site-specific COCs are identical to naturally occurring and/or anthropogenic chemicals that are present, differentiating the contribution of each source may be a difficult, yet necessary, task in formulating site investigation and risk management plans.

Determination of background concentrations for certain chemicals detected at a site is a very important aspect of establishing the scope of site-specific chemicals of concern (COC) and determining risk-based remediation levels for soil and groundwater. Chemicals not related to past or current site activities may be present at a site, hence, it is important to determine the background concentrations for those specific chemicals. Further, for site related chemicals, background concentrations may be present that are greater than the target risk-based levels. In such cases, determinations will be needed as to whether site remediation will be predicated on background or risk-based levels to protect human health, public welfare and the environment. Where background concentrations are above risk-based concentrations, it may not be feasible or practical to remediate sites to the target risk–based levels due to technical impracticability, lack of cost-effectiveness and the potential for recontamination of remediated areas by surrounding areas with elevated background concentrations.

M.2. METHODOLOGY

Prior to determining the site-specific background concentration for any chemical, the following approach should be followed to determine if a background determination is necessary.

First, it should be determined if the chemicals present on-site are due to site-related activities, activities at adjacent/nearby sites and/or may be naturally occurring or due to local/regional anthropogenic activities. . Historical research, literature searches and interviews should be performed to determine the past and current activities at the site and adjacent properties and identify any local or regional background information that can be used to establish a definitive list of the site-specific chemicals of concern.

This guidance establishes three levels of risk-based criteria:

1. Default Target Levels/WQC
2. Tier 1 Risk-Based Target Levels
3. Site-Specific Risk-Based Target Levels

Determination of background concentrations in soil and groundwater may be necessary for chemicals that exceed Default Target Levels or Tier 1 Target Levels, if those chemicals are expected to be present in the ambient environment because they are naturally occurring and/or are present as a result of anthropogenic activities.

In determining site-specific background levels, the area targeted for sampling should be on or in close proximity to the site. The selected area should not have been impacted by historical or current site or nearby activities. Sampling of off-site anthropogenic fill materials should also be avoided, though this may not always be possible or practical. .

There are a number of issues related to selection of a background area for sampling. The following points must be taken into consideration:

a) **Background soil samples should be taken from an area with soil characteristics similar to the site**. For example, background soil samples for sites in alluvial settings should not be taken from nearby uplands as those soils may have a significantly different chemical composition. Because of the heterogeneity of soils, multiple background soil samples may be necessary to establish a range and/or average background concentration for a COC. As soil characteristics may vary both laterally and vertically, it may be necessary to determine background concentrations for different stratigraphic intervals or for areas of impact that are widely separated by unimpacted areas.

   Because of these considerations, it is important to ensure that factors that affect the concentrations of chemicals in the soil are considered when collecting samples from the site and off-site. To the extent possible, off-site background soil samples taken for comparison with on-site impacted soils should be taken from identical/similar soil associations at the same time of the year. However, timing of the sampling may not be critical if the COCs are metals or other chemical compounds for which concentrations are expected to remain relatively constant over time.

   Grid sampling can be an effective way of obtaining representative background soil samples; however, care must be taken to avoid including samples from impacted areas, or samples from areas or intervals that are significantly dissimilar considering the physical, chemical, and biological characteristics of the soil.

b) **Background groundwater samples should be taken from identical/ similar groundwater bearing zones.** To determine background concentrations of chemicals in ground water, sampling should generally be conducted for a minimum of one year over four consecutive quarters unless a different schedule is approved by the department. This is necessary to account for seasonal and temporal variations in groundwater quality Wells used in the background determination must be:
   - Located in areas not affected by releases related to the site,
   - Screened in the same hydrostratigraphic unit that is contaminated on site,
   - Located up gradient from the release area(s),
   - Sufficient in number to account for all possible off-site releases; and
   - Sufficient in number to adequately characterize the hydrogeologic setting.

c) **Determination of background area:** The background area must be comparable to the soil and groundwater characteristics at the site. The background area must be in close proximity to the site and not be impacted by the site or nearby activities. Establishment of acceptable background areas can vary significantly from metropolitan to non-metropolitan areas.

d) **Evaluation of land use and prior history is important:** It is important to collect information regarding current and historical land use at and near the site, in order to determine whether prior human activities could have contributed to background concentrations, and to the presence of certain chemicals unrelated to activities at the site or from nearby sites. Similarly, if anthropogenic fill materials are present, it is important to recognize the potential for contaminants because of the presence of fill materials.

e) **Appropriate number of samples:** It is important to collect an appropriate number of samples for the statistical method being used to determine representative background concentrations, and in consideration of site-specific conditions. The sampling strategy should be designed to determine background concentrations that are truly representative of the site vicinity. Care should be taken if composite sampling will be used to reduce the total number of samples, such that the composites are representative of background conditions and do not create biased results. The number of samples to be obtained must be supported by a valid sampling strategy that has been approved by the department.

Any statistically valid approach approved by the department can be used to develop representative site-specific background concentrations. The approach must be appropriate for the characteristics of the data set being evaluated.

M.3. APPROVAL

The basis for approval of a site-specific background concentration for a specific chemical shall be determined by review of the following criteria:

a) Evaluation of all samples used in the background data set to determine if appropriately representative of site conditions based on locations, depths, number of samples, sampling methods, and laboratory analysis methods.

b) Evaluation from toxicological /risk-assessment standpoints to determine if the background concentrations are inherently too high from potential exposure and current/future land use perspectives.

c) Verification of the statistical methodology and assumptions used and results obtained.

M.4. APPLICATION

An approved site-specific background concentration of a chemical may be used in development of site-specific screening and remediation strategies at any level (i.e., Default Target Levels, Tier 1 Target Levels, Site-Specific Risk Assessment Target Levels). In some cases, the site-specific background concentrations will be higher than the risk-based remediation level. For example, the risk-based concentration of a chemical in soil related to site-specific activities may be lower than the naturally occurring concentration of that chemical in the same soil. In that situation, the soil background concentration, rather than a risk-based concentration, may drive the remediation.

If the site-specific background concentration for a specific chemical is higher than the concentrations detected in all other samples, then that chemical may be dropped from further consideration in the development of site-specific remediation goals.

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APPENDIX N
CLEANUP LEVELS FOR SURFACES AND BUILDING INTERIORS

N.1. ASBESTOS ABATEMENT

Clearance criteria for asbestos abatement projects that occur within the confines of a building are specified at 10 CSR 10-6.240(H). The department must approve any deviations from these clearance criteria.

N.2. LEAD ABATEMENT

For lead abatement projects that occur within the confines of a building the clearance criteria for dust wipe samples are as follows:

<u>Residential</u>
40 micrograms of lead per square foot for uncarpeted floors,
250 micrograms of lead per square foot for windowsills, and
800 micrograms of lead per square foot for window wells.

<u>Non-Residential</u>
200 micrograms of lead per square foot for floors,
500 micrograms of lead per square foot for windowsills, and
800 micrograms of lead per square foot for window wells.

The department must approve any deviations from these clearance criteria.

Note: The Residential clearance criteria are derived from 40 CFR 745.65(b), as proposed in the June 3, 1998 *Federal Register*. The Non-Residential clearance criteria are derived from the Missouri Office of Administration's Lead Abatement Specifications.

N.3. PCB-CONTAMINATED STRUCTURES

For PCB-contaminated concrete, the cleanup criteria shall be 10 ppm for destructive core sampling and 10 $\mu g/100\ cm^2$ for surface wipe sampling. Because concrete is permeable, destructive core sampling or its equivalent is required for PCB-contaminated concrete. The wipe sampling may be optional. The department may consider higher cleanup criteria for PCB-contaminated concrete if the concrete is effectively encapsulated with an impermeable surface coating. In this case, a restrictive covenant would be required to ensure long-term maintenance of the surface coating.

For PCB contamination on impervious solid surfaces, such as a metal wall, the cleanup criteria shall be 10 $\mu g/100\ cm^2$ for a surface wipe sample.

Note: The 10 $\mu g/100\ cm^2$ criteria are derived from the USEPA's PCB Spill Cleanup Policy, 40 CFR 761, Subpart G. The USEPA's Spill Cleanup Policy does not prescribe destructive core sampling for PCB-contaminated concrete. Wipe sampling alone is not sufficient to verify cleanup of PCB-contaminated concrete. It is possible to remove PCBs from the surface of the concrete through solvent washing and leave behind significant PCB contamination deeper in the concrete. With time, PCBs may again migrate to the surface, creating a potential exposure. This scenario illustrates the need for destructive core sampling.

APPENDIX O
SOIL TYPE DETERMINATION GUIDELINES
March 18, 2005

O.1. BACKGROUND

When initially implemented, the Missouri Risk-Based Corrective Action (MRBCA) process included one set of Tier 1 Risk-Based Target Levels (RBTLs). This initial set of RBTLs applied to all media, receptor, and exposure pathways addressed by the MRBCA process. The Missouri Department of Natural Resources (MDNR) has since put into effect new Tier 1 RBTLs. The new RBTLs, for both the Departmental and Tanks MRBCA Guidance, are soil type dependent. This means that the RBTLs applicable to a specific site depend on the type of soil present at the site. Where initially there was one set of Tier 1 RBTLs, there are now three: one set for Type 1 or sandy soils, one for Type 2 or silty soils, and one for Type 3 or clayey soils.

Each of the three Tier 1 soil types is a virtual composite of several soils having similar properties. Using the properties of these individual soils, the department developed average porosity and water content values for each soil type. Table 1 below shows the specific soils considered in developing each general soil type and the average porosity and water content values of each general soil type.

Table 1

Soil type	Soil (SCS Classification)	Porosity (avg.)	Water content (avg.)
1	Sand	0.38	0.08
	Loamy sand		
	Sandy loam		
2	Clay loam	0.44	0.17
	Silt		
	Loam		
	Silty clay loam		
	Sandy clay loam		
	Silt loam		
3	Clay	0.44	0.21
	Silty clay		
	Sandy clay		

As the table indicates, the specific soil types are identified in accordance with Soil Conservation Service (SCS, now Natural Resource Conservation Service) classifications. Therefore, the SCS classification system, including the US Department of Agriculture (USDA) textural classification chart, must be used in determining a site-specific soil type. A copy of the USDA chart is found below as Figure 1.

In developing the three Tier 1 general soil types, MDNR primarily considered the moisture content and total porosity of each. Even so, soil porosity and moisture content measurements are not required in determining the type of soil present at a specific site, though the evaluator might find this information useful. These guidelines stipulate that soil type determinations be based on soil grain size analyses and the evaluation of boring logs.

O.2. DETERMINATION GUIDELINES AND REQUIREMENTS

The soil type determination must be applicable to the entire geographical extent of the site (that is, the entire area of contamination as determined by the application of the delineation criteria stipulated in the MRBCA guidance document) and 10 feet below the vertical extent of the soil contamination. If contamination originating at the site has resulted in groundwater contamination, the soil type determination shall apply to the entire soil column from the surface to the top of the saturated zone (i.e., the vadose zone).

A Missouri-registered geologist (RG) or qualified Missouri-licensed professional engineer (PE) must seal the soil type determination applicable to a site being evaluated under the MRBCA process. In determining the soil type, the RG or PE, or someone under the direct supervision of a RG or PE, shall employ all reasonable and appropriate professional standards applicable to soil type identification. The use of Method 3A1, Particle-Size Analysis, found in the *Soil Survey Laboratory Methods Manual, Soil Investigation Report, Number 42, Volume 3.0, January 1996* or the American Society for Testing and Materials (ASTM) standard D422-63 (2002), *Standard Test Method for Particle Size Analysis of Soils*, is a required component of the soil type determination process. With either method, the results must be plotted on the USDA textural classification chart, a modified copy of which is included below as Figure 1, in order to determine the appropriate soil type.

For samples to be analyzed using one of the aforementioned methods, MDNR recommends that the sample be collected from a portion of the site free of significant contamination. Because geotechnical laboratories generally are not set up to manage contaminated samples, ideally the samples should be collected outside the area of contamination, though the samples must come from an area having the same soil type as is found within the area of contamination. Regardless of where the samples are collected, they must be representative of soils within the area of contamination. Samples may be collected concurrently with the collection of samples to be analyzed for the various Tier 2 geotechnical parameters.

For sites where site characterization activities are complete at the time these guidelines are made generally available (i.e., the date on page one), the evaluator may make a soil type determination using existing site characterization data, specifically boring logs. For such sites, MDNR will not require grain size analyses provided that the existing site characterization data is sufficient to allow the evaluator to accurately determine soil type. All soil type determinations made based solely on existing site characterization data must be thoroughly documented and explained. If MDNR determines that the existing site characterization data is not adequate to support a soil type determination, MDNR may require further soil type evaluation, including the collection of soil samples for grain size analysis.

In addition to analyzing one or more representative soil samples as described above, in order to ensure that all soil types at a site are identified, one or more borings or probes must be advanced to a depth at least 10 feet below the vertical extent of soil contamination or, if groundwater is contaminated by constituents originating at the site, to the top of the saturated zone. Each boring or probe must be comprehensively logged at intervals sufficient to account for all significant changes in soil stratigraphy, including the identification of discrete seams less than three inches thick. In certain cases, the advancement of borings or probes into the saturated zone might be necessary to ensure accurate identification of all soil types at a given site. The boring log or logs shall be evaluated and considered by the RG or PE in determining the overall site-specific soil type.

Soil heterogeneity shall be accounted for in the determination process and appropriately considered in making a final soil type determination. Soil testing conducted as a part of the soil type determination process must be demonstrably representative of all soil types overlying and immediately underling soil and groundwater contamination at a specific site. The person making the soil type determination shall be responsible for determining the number and distribution of soil samples necessary to ensure that all relevant soil types at a site are accurately identified such that the overall soil type can be determined. In all cases, at least one sample representative of the soil column from the surface to at least 10 feet below the vertical extent of the soil contamination, or, if groundwater is contaminated, to the top of the saturated zone, shall be collected for analysis by one of the aforementioned analytical methods. Where significant soil heterogeneity exists, MDNR may require that more than one sample be collected and analyzed.

In situations where the type of soil at a specific site is not one of the three soil types discussed above, or where the degree of soil heterogeneity is such that the soil at a site cannot be accurately identified as any one particular type, MDNR will require that the RBTLs for Soil Type 1 apply to the site.

In situations where two or three soil types exist at a site in approximately the same amounts, MDNR will require that the RBTLs associated with the most conservative of the Soil Types apply to the site. For the purposes of the MRBCA process, Soil Type 1 is considered the most conservative, followed by Soil Type 2 and, the least conservative, Soil Type 3.

As is an option with all sites, sites having two or three soil types in approximately the same amounts may be evaluated under Tier 2 of the MRBCA process. Under Tier 2, the type of soil at a site need not necessarily be identified in accordance with these guidelines. Instead, specific fate and transport properties of the soil or soils shall be identified via the collection of an appropriate number of representative soil samples for analysis of the geotechnical properties discussed in Section 5.0 of the MRBCA guidance.

O.3. REPORTING

At present, MDNR does not have electronic forms available for documenting soil type determinations. We anticipate that such forms will be available in the future. Until that time, soil type determinations shall be documented as discussed below.

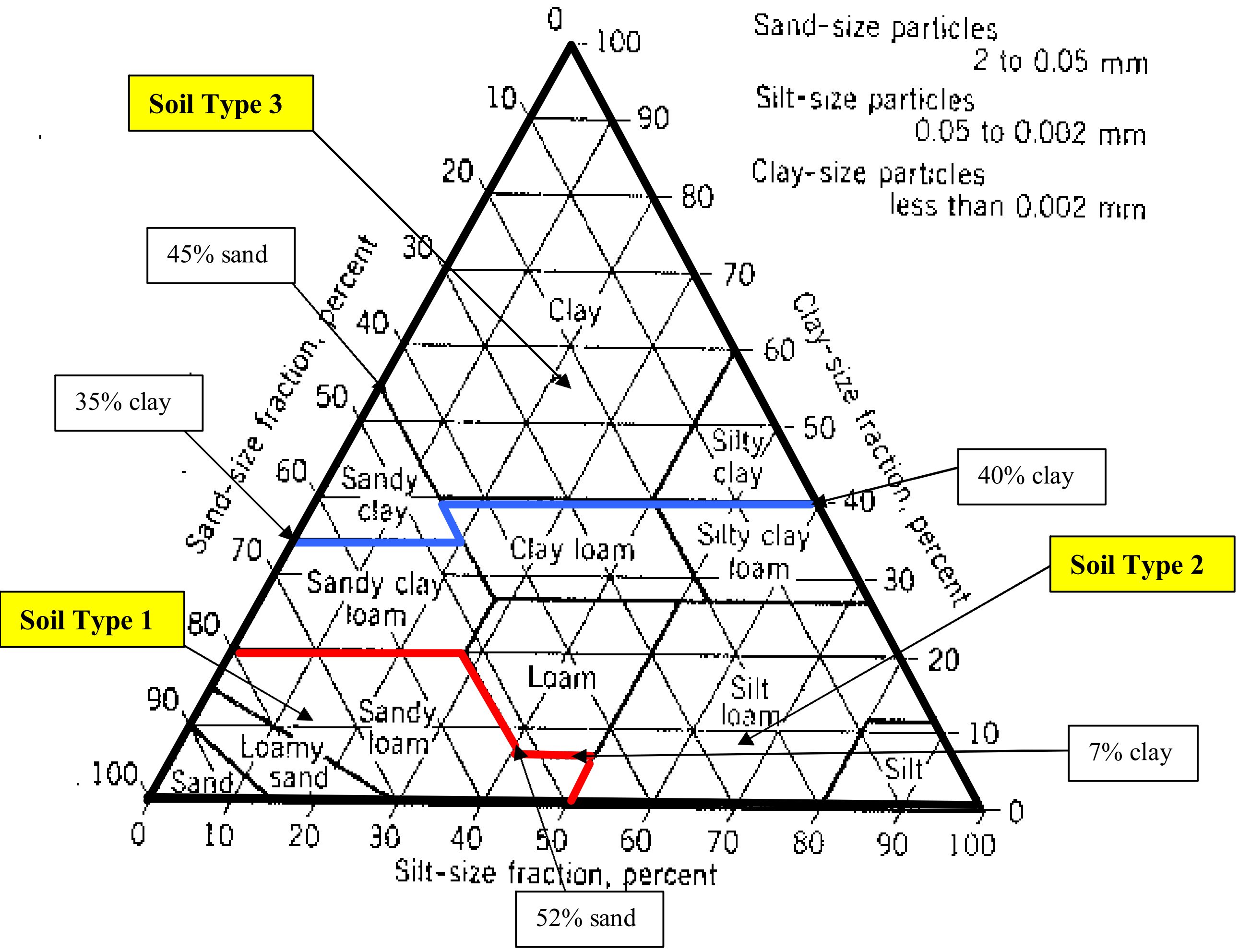
A report documenting the soil type and determination process must be submitted to the MDNR. The report may either stand-alone or be included as a discrete part of a site investigation or MRBCA Tier 1 or Tier 2 report (i.e., as an appendix or attachment). In any case, the report shall, at a minimum, include the following:

- A narrative section explaining how the soil type determination was made and identifying the soil type or types identified at the site. Include in this section the rationale for soil sample locations and a narrative discussion of the soil stratigraphy of the site as determined through the evaluation of boring logs;
- All applicable and necessary supporting documentation, including, at a minimum, boring logs, laboratory analytical results, chain of custody forms, cross-sectional diagrams, and a site map showing the location(s) where soil samples used in the soil determination process were collected. Where more than one soil type is present at a site, the report shall include a site map or cross sectional diagram showing the distribution of each soil type across the site; and
- The seal and signature of a Missouri registered RG or PE.

MDNR prefers that the soil type determination report be submitted prior to the Tier 1 or Tier 2 report, as the target levels applicable to a site will be dependent on the type of soil present at the site. We recommend that the soil type determination report be submitted with or as a part of the initial site characterization report.

If site characterization is complete (i.e., all contamination has been defined in accordance with the provisions of the MRBCA guidance document), the evaluator should submit a site characterization report, a MRBCA risk assessment report, and a work plan for corrective action, ongoing monitoring, or other necessary activities.

Figure 1: USDA Textural Classification Chart



<u>Soil Descriptions Using Figure 1</u>

- Sand: >85% sand
- Loamy sand: 70 to 91% sand
- Sandy loam: 7 to 20% clay, >52% sand, or <7% clay, <50% silt, and >43% sand
- Sandy clay loam: 20 to 35% clay, <28% silt, >45% sand
- Loam: 7 to 27% clay, 28 to 50% silt, and 52% or less sand
- Silt loam: 50% or more silt and 12 to 27% clay, or 50 to 80% silt and <12% clay
- Silt: 80% or more silt and <12% clay
- Silty clay loam: 27 to 40% clay and 20% or less sand
- Clay loam: 27 to 40% clay and 20 to 46% sand
- Sandy clay: 35% or more clay and 45% or more sand
- Silty clay: 40% or more clay and 40% or more silt
- Clay: 40% or more clay, 45% or less sand, and <40% silt

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